

2 FEB 1989

# EDN<sup>®</sup>

CASE update

Chopper-stabilized op amps

Troubleshooting (Part II)

Technical-article  
database index

ELECTRONIC TECHNOLOGY FOR ENGINEERS AND ENGINEERING MANAGERS

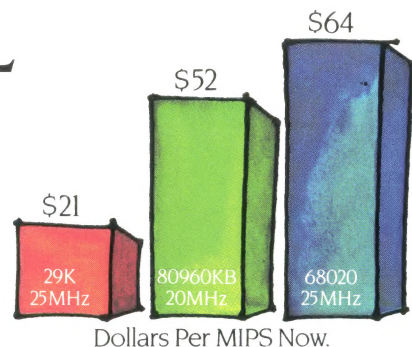
## Speech-recognition products span the man/machine gap





simulators. Hardware debug module by Step Engineering. All available from AMD.

Behavioral models from Logic Automation. Real time OS by Ready Systems. Logic analyzer interfaces from HP. And more.

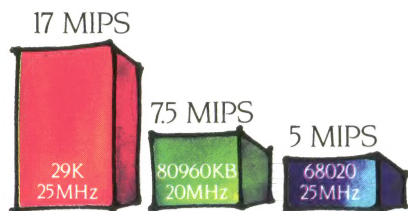


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CIRCLE NO 120





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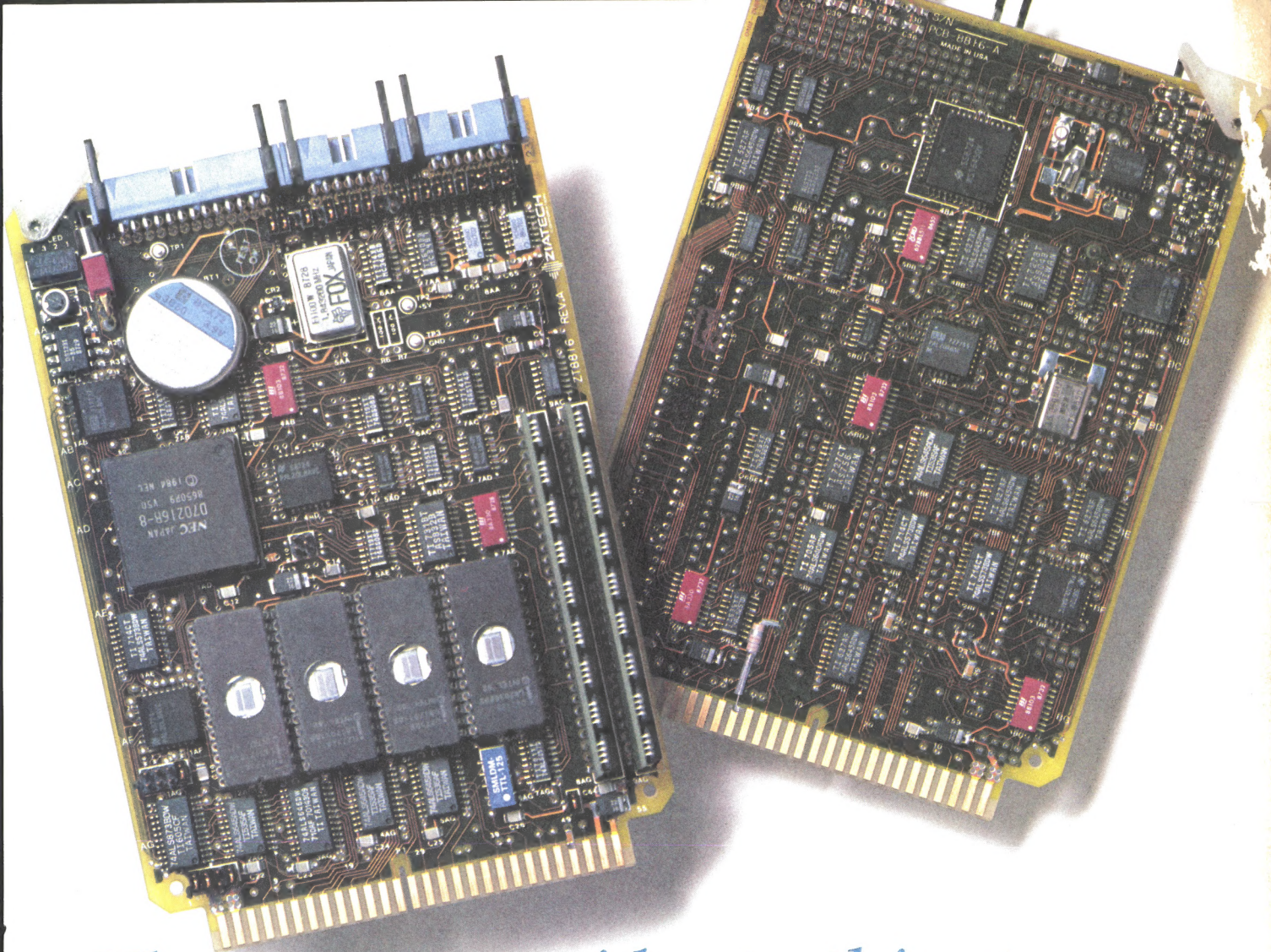
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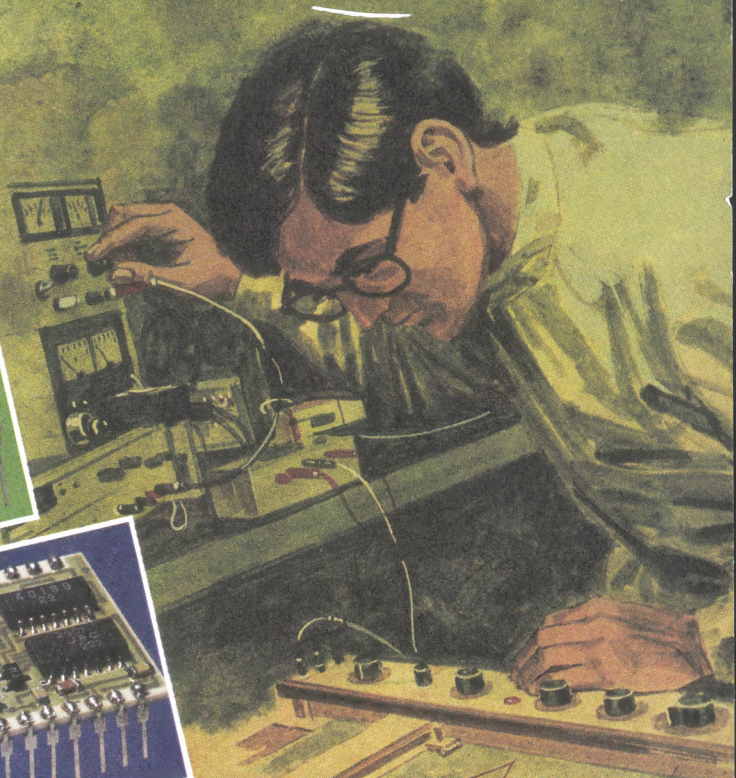
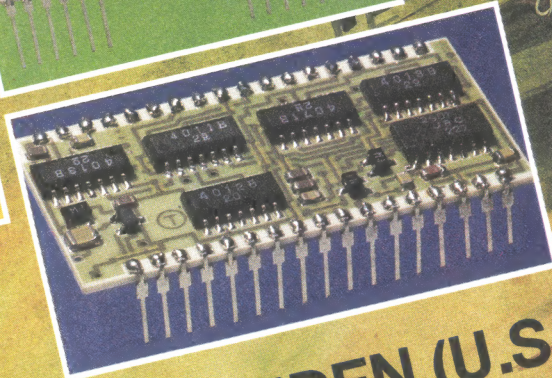
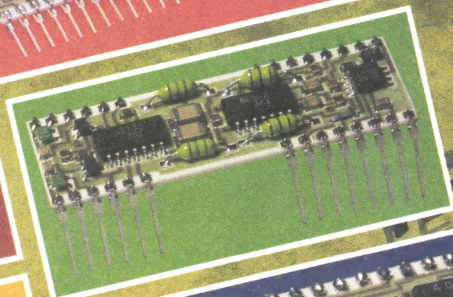
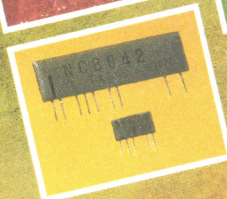
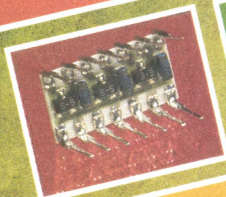
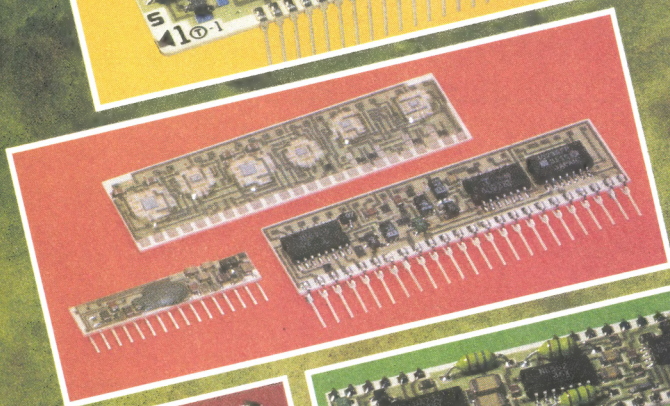
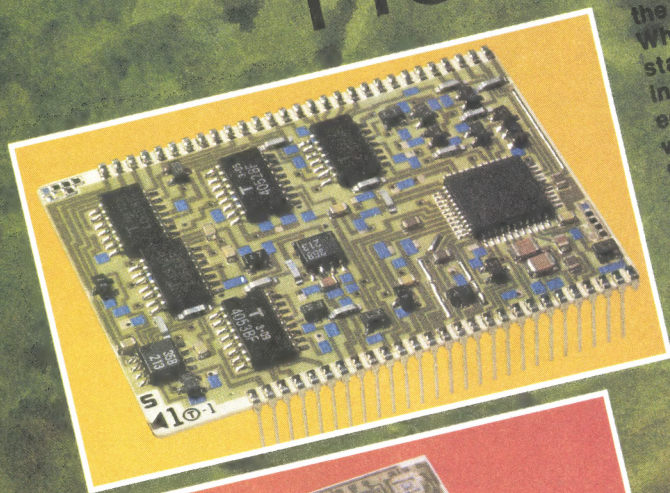




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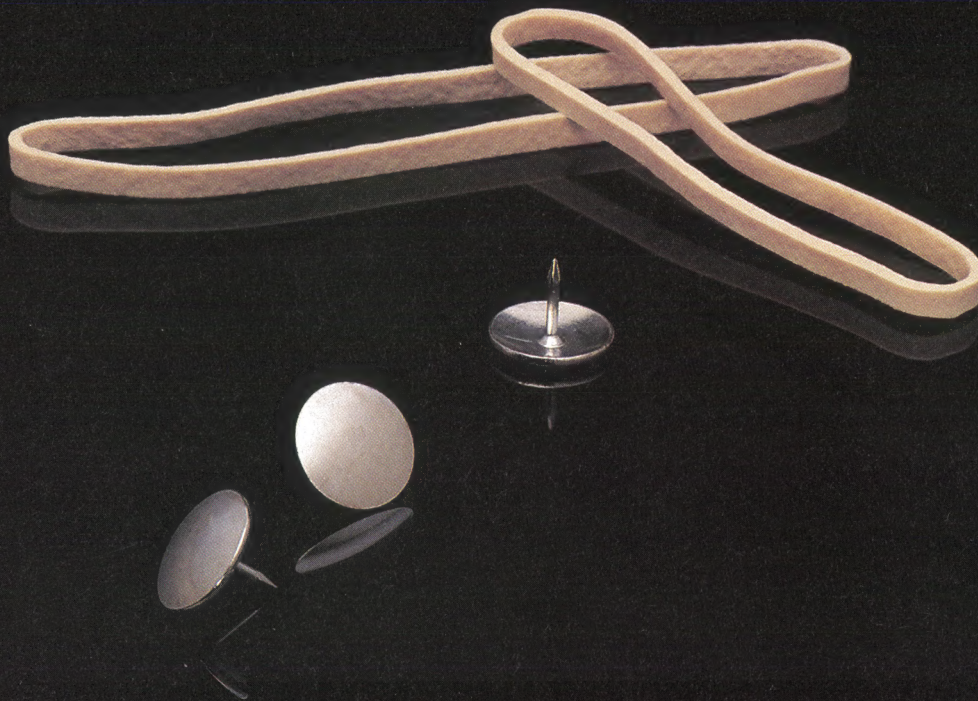
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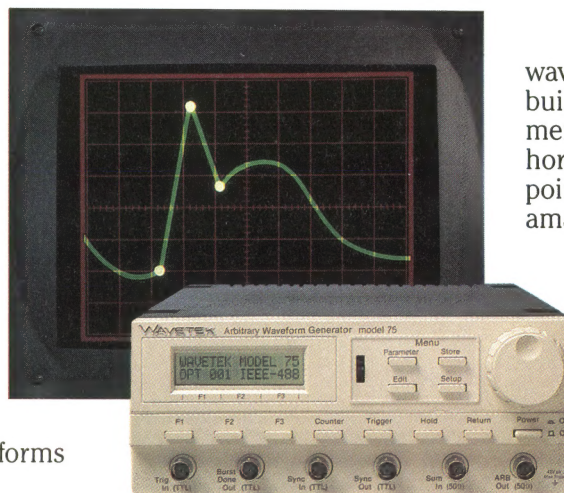


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waveforms. Or use one of the nine built-in functions. The Model 75 memory provides a grid of 8,000 horizontal and 4,000 vertical points for reproducing signals with amazing purity.

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For literature or a hands-on demonstration of Model 75, call (619) 279-2200.



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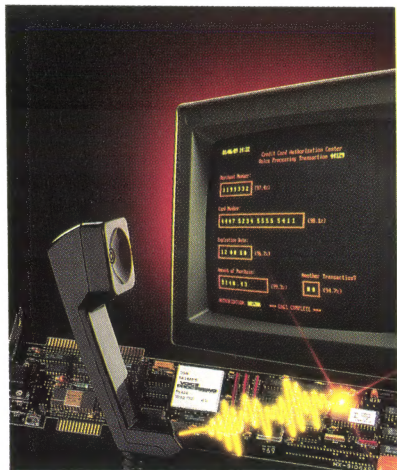
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CIRCLE NO 109





**On the cover:** Many kinds of data-entry applications can take advantage of commercially available speech-recognition products. See pg 112. (Photo courtesy Voice Processing Systems)

## SPECIAL REPORT

### Speech-recognition products

112

Long the dream of the data-entry operator, true speech recognition is on its way to becoming a reality. Commercially available products operate with a high degree of accuracy in many acoustically noisy environments.—*John A Gallant, Associate Editor*

## DESIGN FEATURES

### Designer's guide to op-amp feedback circuits—Part 1

131

Many engineers will benefit from a discussion of feedback effects and the construction of feedback plots for operational amplifiers. Part 1 of this series limits its discussion to single-stage amplifiers.—*Jerald G Graeme, Burr-Brown Corp*

### FFT analyzers make spectrum analysis a snap

149

Although swept-spectrum analyzers and FFT analyzers arrive at essentially the same result, their methods differ. The FFT analyzer and its method offer some distinct advantages.—*George Dovel, Hewlett-Packard Co*

### Troubleshooting analog circuits—Part 2

157

As discussed in Part 1 of this multipart series, the most important thing you need for effective troubleshooting is your wits. Part 2 discusses the equipment necessary for most general troubleshooting tasks.—*Robert A Pease, National Semiconductor Corp*

### Drive scheme holds key to dc motor performance

171

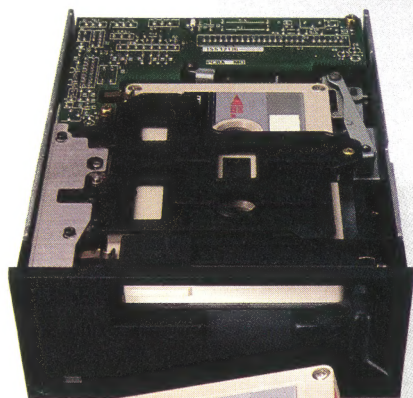
To optimize the performance of a brushless dc servomotor system, you must select the proper motor drive scheme. Two popular drive options illustrate how output torque, current ripple, and PWM techniques can affect performance.—*Malcolm B McCormick, Inland Motor*

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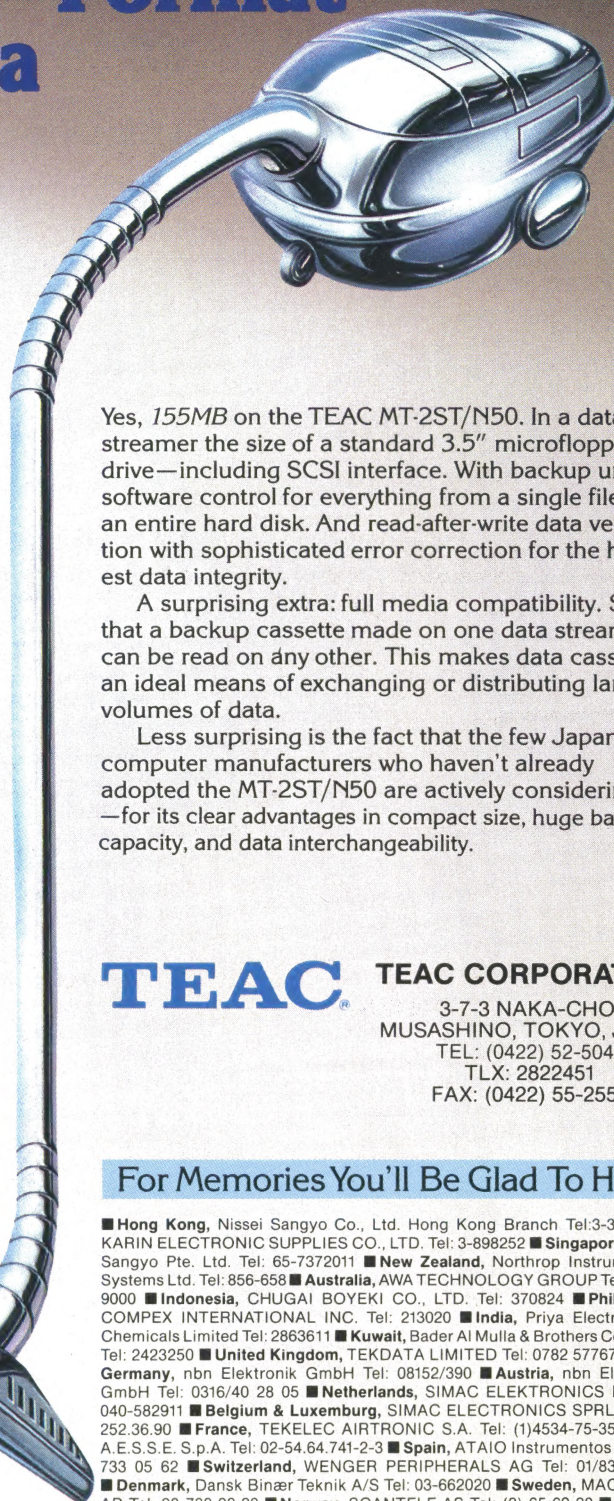
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A surprising extra: full media compatibility. So that a backup cassette made on one data streamer can be read on any other. This makes data cassettes an ideal means of exchanging or distributing large volumes of data.

Less surprising is the fact that the few Japanese computer manufacturers who haven't already adopted the MT-2ST/N50 are actively considering it. —for its clear advantages in compact size, huge backup capacity, and data interchangeability.

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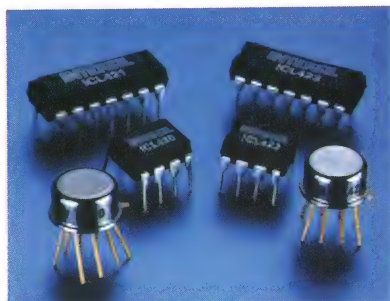
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**Low offset-voltage drift** is probably the most attractive characteristic of chopper-stabilized op amps (pg 91).

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## TECHNOLOGY UPDATE

### CASE demands much but gives high returns 67

Users find that CASE tools may not shorten your development time—but for large projects, they reduce both the number of errors and the burden of documentation.—*Chris Terry, Associate Editor*

### Chopper-stabilized op amps: Improvements 91 make precision amps easier

Chopper-stabilized op amps that solve the problems of excessive clock noise, long overload recovery times, and external holding capacitors have begun appearing over the past 18 months. These new op amps make it easier to build high-precision circuits that use chopper-stabilized devices.—*Richard A Quinnell, Regional Editor*

## PRODUCT UPDATE

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## DESIGN IDEAS

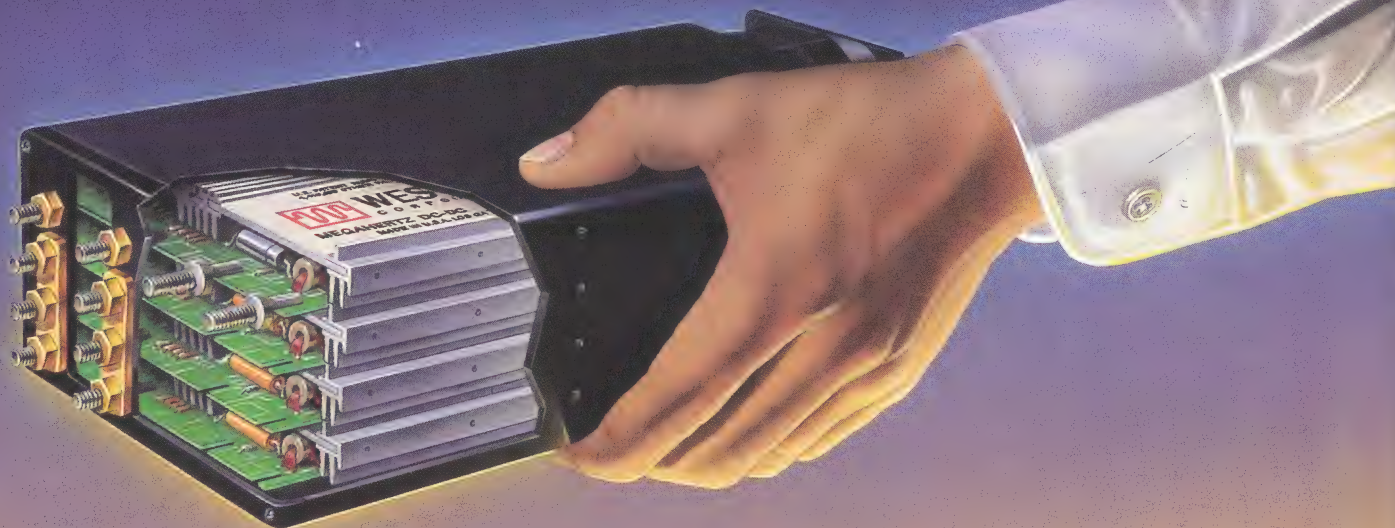
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# THE POWER SUPPLY



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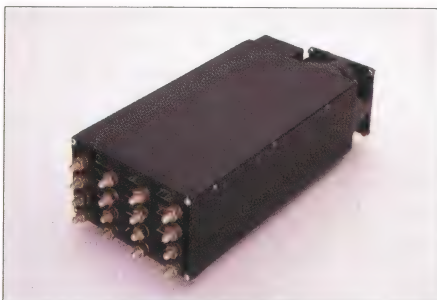
### THE WESTCOR STAKPAK™. NEW GENERATION 250 TO 1200 WATT SINGLE OR MULTIPLE OUTPUT OFF-LINE SWITCHER. 3.2 X 5.5 X 11.4 INCH CASE. FAN-COOLED.

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The StakPak's 8 module output section can be factory configured in virtually an infinite number of voltage, current and power combinations. Special models providing between 250 to 1200 watts and outputs from 2 to 95 VDC are available.

Other features include outstanding electrical performance; UL, CSA, VDE safety agency approval (in process); variable speed fan option for low ambient noise environments and 3 phase or DC input options. Indeed, with unprecedented power density, versatility and new features, the StakPak redefines power packaging. Please contact Westcor for a data sheet, pricing and additional information.



### STANDARD 1200 WATT STAKPAK MODELS (110/220 VAC input)

| Model                | Output Voltage (VDC) and Maximum Current (amperes) per Channel |         |         |        |        |
|----------------------|----------------------------------------------------------------|---------|---------|--------|--------|
|                      | #1                                                             | #2      | #3      | #4     | #5     |
| <b>Single Output</b> |                                                                |         |         |        |        |
| SP1-1801             | 2 @ 240                                                        |         |         |        |        |
| SP1-1802             | 5 @ 240                                                        |         |         |        |        |
| SP1-1803             | 12 @ 100                                                       |         |         |        |        |
| SP1-1804             | 15 @ 80                                                        |         |         |        |        |
| SP1-1805             | 24 @ 50                                                        |         |         |        |        |
| SP1-1806             | 28 @ 42                                                        |         |         |        |        |
| SP1-1807             | 48 @ 25                                                        |         |         |        |        |
| <b>Dual Output</b>   |                                                                |         |         |        |        |
| SP2-1801             | 2 @ 120                                                        | 5 @ 120 |         |        |        |
| SP2-1802             | 5 @ 120                                                        | 5 @ 120 |         |        |        |
| SP2-1803             | 5 @ 120                                                        | 12 @ 66 |         |        |        |
| SP2-1804             | 12 @ 66                                                        | 12 @ 66 |         |        |        |
| SP2-1805             | 15 @ 53                                                        | 15 @ 53 |         |        |        |
| <b>Triple Output</b> |                                                                |         |         |        |        |
| SP3-1801             | 5 @ 180                                                        | 12 @ 16 | 12 @ 16 |        |        |
| SP3-1802             | 5 @ 150                                                        | 12 @ 33 | 12 @ 16 |        |        |
| SP3-1803             | 5 @ 180                                                        | 15 @ 13 | 15 @ 13 |        |        |
| SP3-1804             | 5 @ 150                                                        | 15 @ 26 | 15 @ 13 |        |        |
| <b>Quad Output</b>   |                                                                |         |         |        |        |
| SP4-1801             | 5 @ 150                                                        | 12 @ 16 | 12 @ 16 | 5 @ 30 |        |
| SP4-1802             | 5 @ 150                                                        | 15 @ 13 | 15 @ 13 | 5 @ 30 |        |
| SP4-1803             | 5 @ 150                                                        | 12 @ 16 | 12 @ 16 | 24 @ 8 |        |
| SP4-1804             | 5 @ 150                                                        | 15 @ 13 | 15 @ 13 | 24 @ 8 |        |
| <b>Five Output</b>   |                                                                |         |         |        |        |
| SP5-1801             | 5 @ 120                                                        | 12 @ 16 | 12 @ 16 | 5 @ 30 | 24 @ 8 |
| SP5-1802             | 5 @ 120                                                        | 15 @ 13 | 15 @ 13 | 5 @ 30 | 24 @ 8 |

Total output power may not exceed 1200 watts for any model, single or multiple output. Lower power StakPak models are available. Please contact the factory.



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## EDITORIAL

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Like spoken languages, computer languages should be open for enhancements and adaptations. No one should "own" languages.

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Odds are 50-50  
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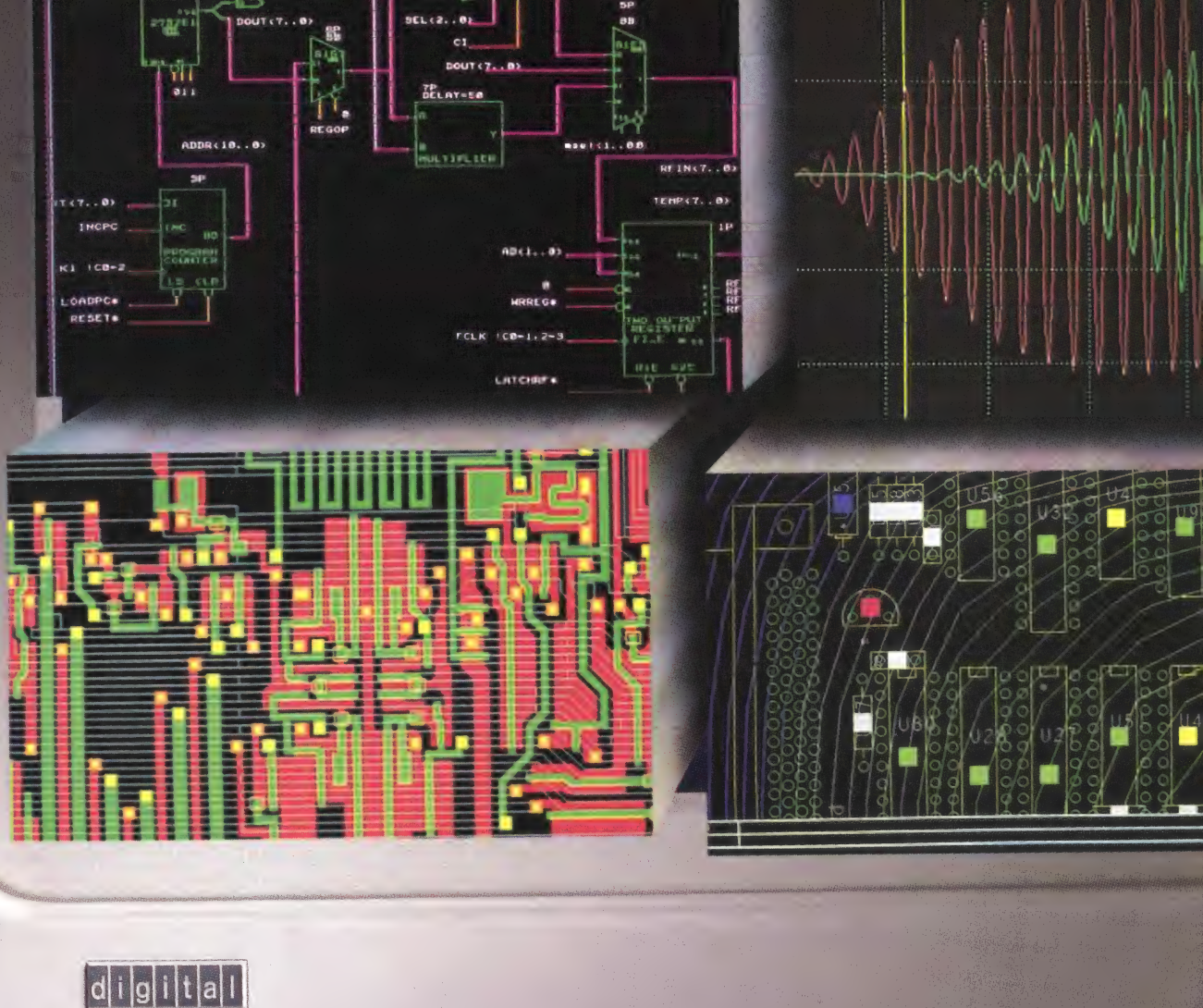
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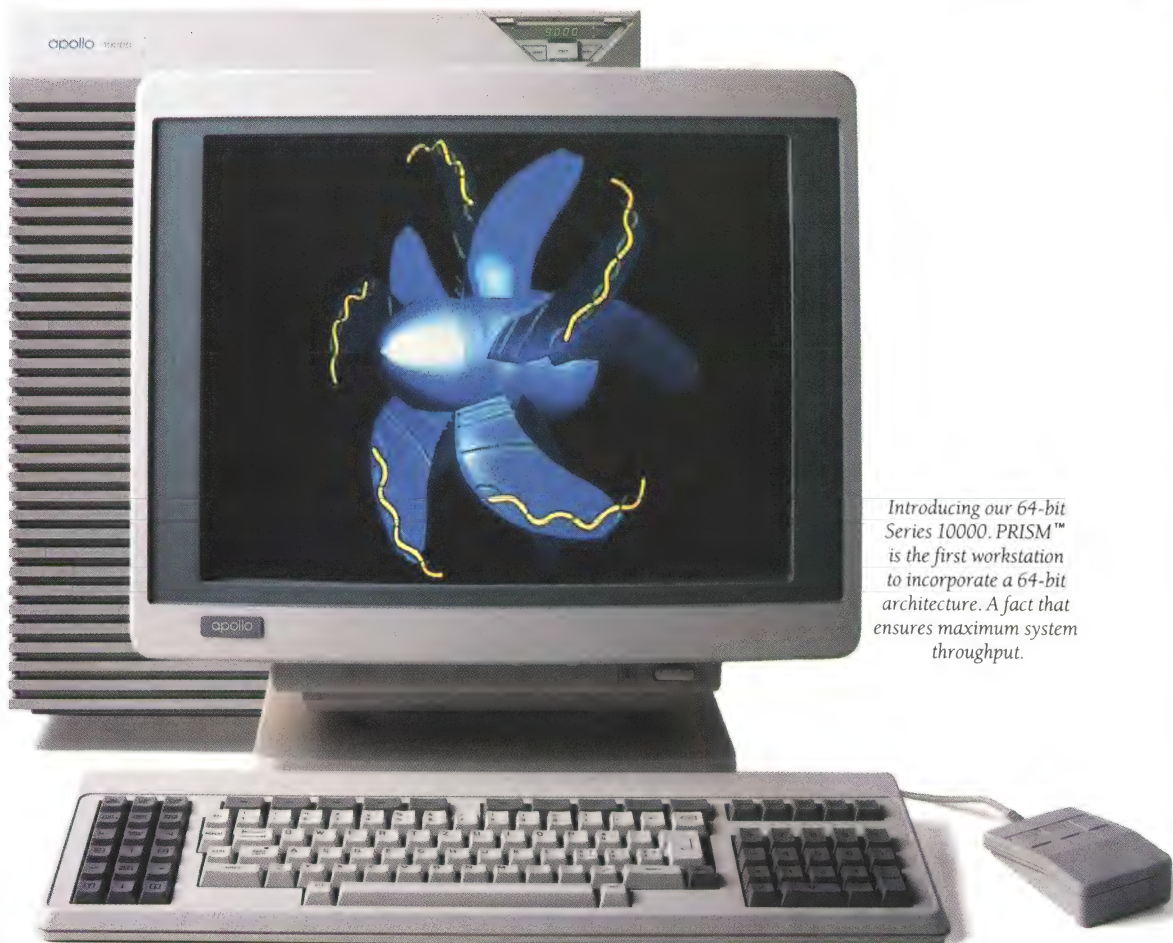
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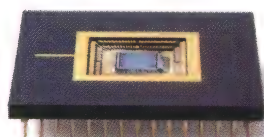
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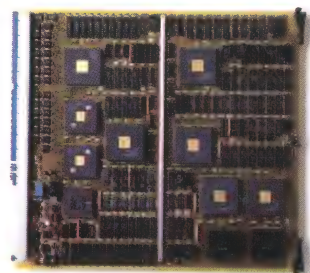


Introducing our 64-bit Series 10000. PRISM™ is the first workstation to incorporate a 64-bit architecture. A fact that ensures maximum system throughput.

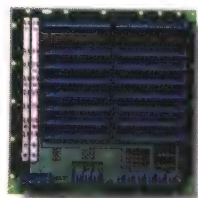
# There comes a time when a better workstation is to be



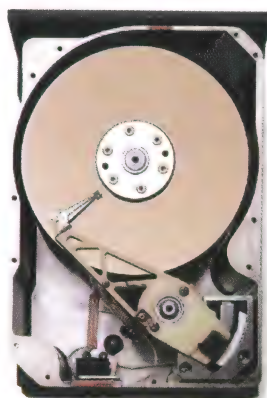
*Faster Chips for Faster Processing:* Advanced CMOS and ECL semiconductor technologies are used throughout to improve performance.



*A Power Plant for Performance:* Each system can have up to four CPUs, delivering performance 100 times that of a VAX® 11/780.



*A High Speed Bus:* Our system bus passes information between CPUs and main memory at 150 million bytes per second.



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*Clever Compilers for Data Flow:* So none of this power goes to waste, sophisticated compilers map existing applications to match the CPU architecture and maximize application throughput.



There are two ways to build a new workstation. The first is to push existing technology as far as it can go. The second is to create a new technology.

And if you've ever wondered which approach yields the more impressive result, the next few paragraphs will resolve the question.

Introducing our Series 10000™ Personal Supercomputer™ and the *PRISM* architecture on which it's based. A new technology that's so efficient, it takes performance previously restricted to supercomputers and packs it into an office-sized workstation.

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Equally impressive is the fact that while our new Personal Supercomputer calls on a brand new technology, it doesn't forsake the old. It lets you work in a distributed UNIX® environment, supporting Berkeley 4.3 and System V.3.

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And it's totally compatible with other Apollo workstations. So you can retain all of your current applications, courtesy of a built-in compiler technology that ensures existing programs run more efficiently.

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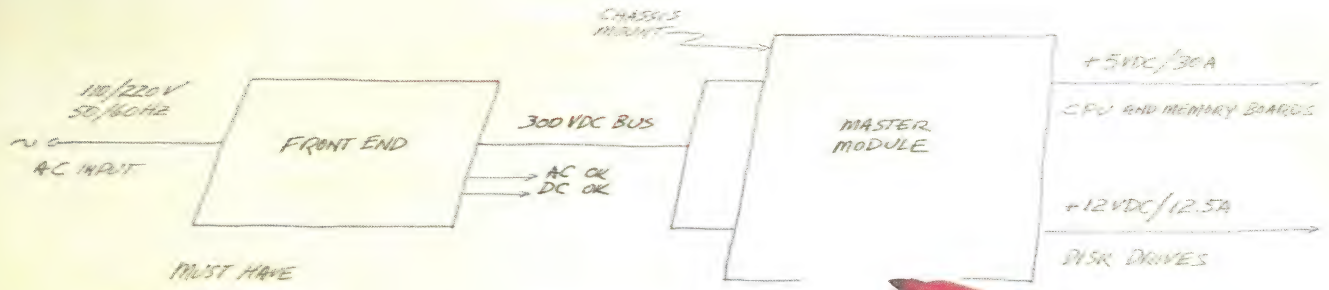
## apollo

For more information, call 1-800-323-1846, and in Massachusetts (1-800-847-1011) or write Apollo, 330 Billerica Road, Chelmsford, MA 01824.

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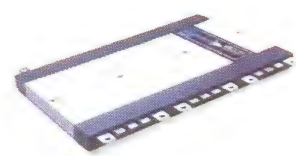
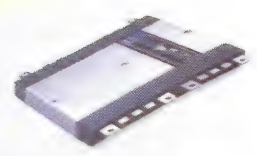


**NEW**



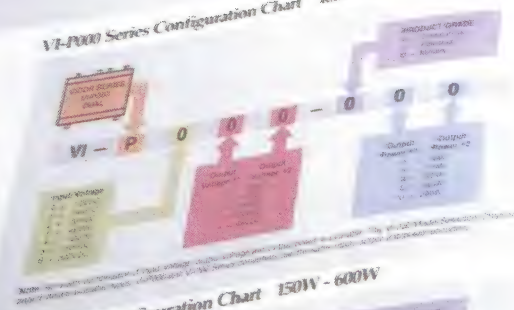
- MUST HAVE**
- UL, CSA, TUV
  - 82% EFFICIENCY
  - HIGH RELIABILITY
  - POWER OK
  - SEQUENCING
  - 50 MS HOLD-UP
  - FCC CLASS-B
  - PROGRAMMABLE OUTPUTS

*VIC*  
ALSO NEED -5.2 VOLTS  
AT 30 AMPS FOR THE  
CONVERTERS TO BE  
CHASSIS MOUNT.  
SEE ME ASAP

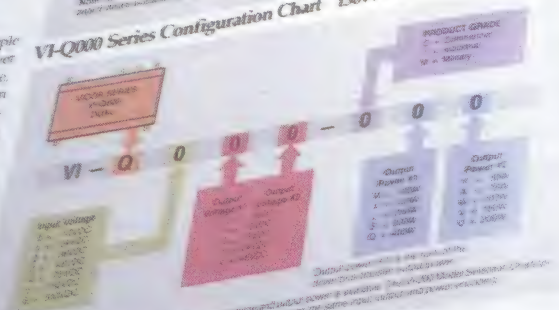


Module Series  
DC-DC Converters  
Triple Output

**VI-P000 Series Configuration Chart 100W - 400W**



**VI-Q000 Series Configuration Chart 150W - 600W**



**Configuration Steps**

- 1 Select Input Voltage
- 2 Select Output Voltage 1
- 3 Select Output Voltage 2
- 4 Select Product Grade
- 5 Select Output Power 1
- 6 Select Output Power 2

48V: VI - P 3 - -  
5V: VI - P 3 0 - -  
12V: VI - P 3 0 1 -  
Commercial: VI - P 3 0 1 - C V  
150W: VI - P 3 0 1 - C V X  
25W: VI - P 3 0 1 - C V X

- 1 Select Input Voltage
- 2 Select Output Voltage 1
- 3 Select Output Voltage 2
- 4 Select Product Grade
- 5 Select Output Power 1
- 6 Select Output Power 2

300V: VI - Q 6 - -  
5V: VI - Q 6 0 - -  
24V: VI - Q 6 0 3 -  
Industrial: VI - Q 6 0 3 - I S  
300W: VI - Q 6 0 3 - I S V  
150W: VI - Q 6 0 3 - I S V

- 1 Select Input Voltage
- 2 Select Output Voltage 1
- 3 Select Output Voltage 2

24V: VI - R 1 - -  
5V: VI - R 1 0 - -  
12V: VI - R 1 0 1 -  
12V: VI - R 1 0 1 -



# Chassis-Mount Modular Power From 50 to 600 Watts!

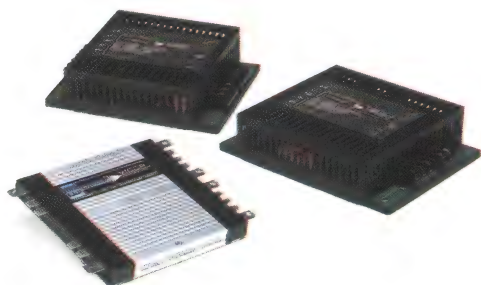
OFF-LINE

*In single or multiple output applications, Vicor's family of chassis-mount, power building blocks provide flexible and predictable solutions to virtually any power system requirement.*

Vicor's family of chassis-mount, off-line front ends, combined with the Mega and Master Module families of chassis-mount DC-DC converters, allow the power system architect to quickly and predictably customize expandable single or multiple output power systems with output power from watts to kilowatts. Modular power building blocks get you up and running in less time, at less cost, while Vicor's unprecedented levels of power density and efficiency result in less wasted space and heat.

## Off-Line Front Ends

Chassis-mount front ends are available in output power ratings of 250, 500, and 750 watts and are designed for direct connection with Vicor's Mega Module and Master Module Series of DC/DC converter modules.



FRONT END SELECTION CHART

| MODEL       | OUTPUT POWER |      |      |
|-------------|--------------|------|------|
|             | 250W         | 500W | 750W |
| VI-FKE6-CUX | ✓            |      |      |
| VI-FKE6-CQX |              | ✓    |      |
| VI-FKE6-CMX |              |      | ✓    |

OPERATING PARAMETERS (ALL MODELS)

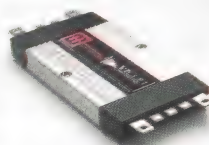
| NOM | INPUT VOLTAGE (VAC) |      |                   |
|-----|---------------------|------|-------------------|
|     | LOW                 | HIGH | TRANSIENT (1 SEC) |
| 110 | 90                  | 135  | 150               |
| 220 | 180                 | 270  | 300               |

Strappable to provide operation from 90 VAC to 270 VAC lines, the front ends feature conducted EMI/RFI filtering to VDE/FCC A & B, 50 msec holdup, active in-rush limiting and a BUS-OK status output. An opto-isolated AC-OK output is provided for advance warning of DC BUS dropout due to AC line failure.

## DC/DC Converter Modules

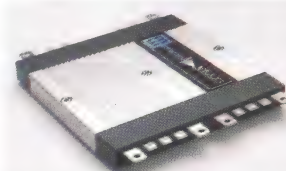
Vicor's Mega Module and Master Module Series of single and multiple output DC-DC converters provide the power system designer with a cost effective, high performance, off-the-shelf solution for applications that might otherwise require a custom supply. These modules incorporate standard VI-200 Series converters in a rugged, chassis-mount package.

### Single Output



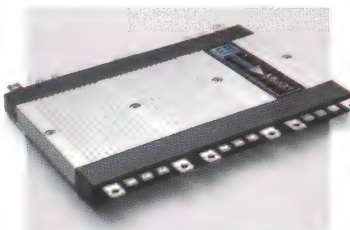
- Single output available from 50 to 200 watts.
- 2.5" x 4.9" x 0.62".

### Single and Dual Outputs



- Single output available from 100 to 400 watts
- Dual outputs from 50 to 200 watts each
- 4.9" x 4.9" x 0.62".

### Single, Dual and Triple Outputs



- Single output available from 150 to 600 watts.
- Dual outputs with the first output from 100 to 400 watts, and the second output from 50 to 200 watts.
- Triple outputs from 50 to 200 watts each.
- 7.3" x 4.9" x 0.62".

Specify your configuration by picking any combination of Vicor's standard output voltages (5, 12, 15, 24, 48 VDC) at the power levels you need. Vicor does the rest. If standard output voltages don't meet your needs, Vicor can provide semi-custom outputs anywhere in the range of 2 to 100 VDC! For complete details and applications information, please refer to the Mega Module and Master Module sections of the Vicor Product Catalog.

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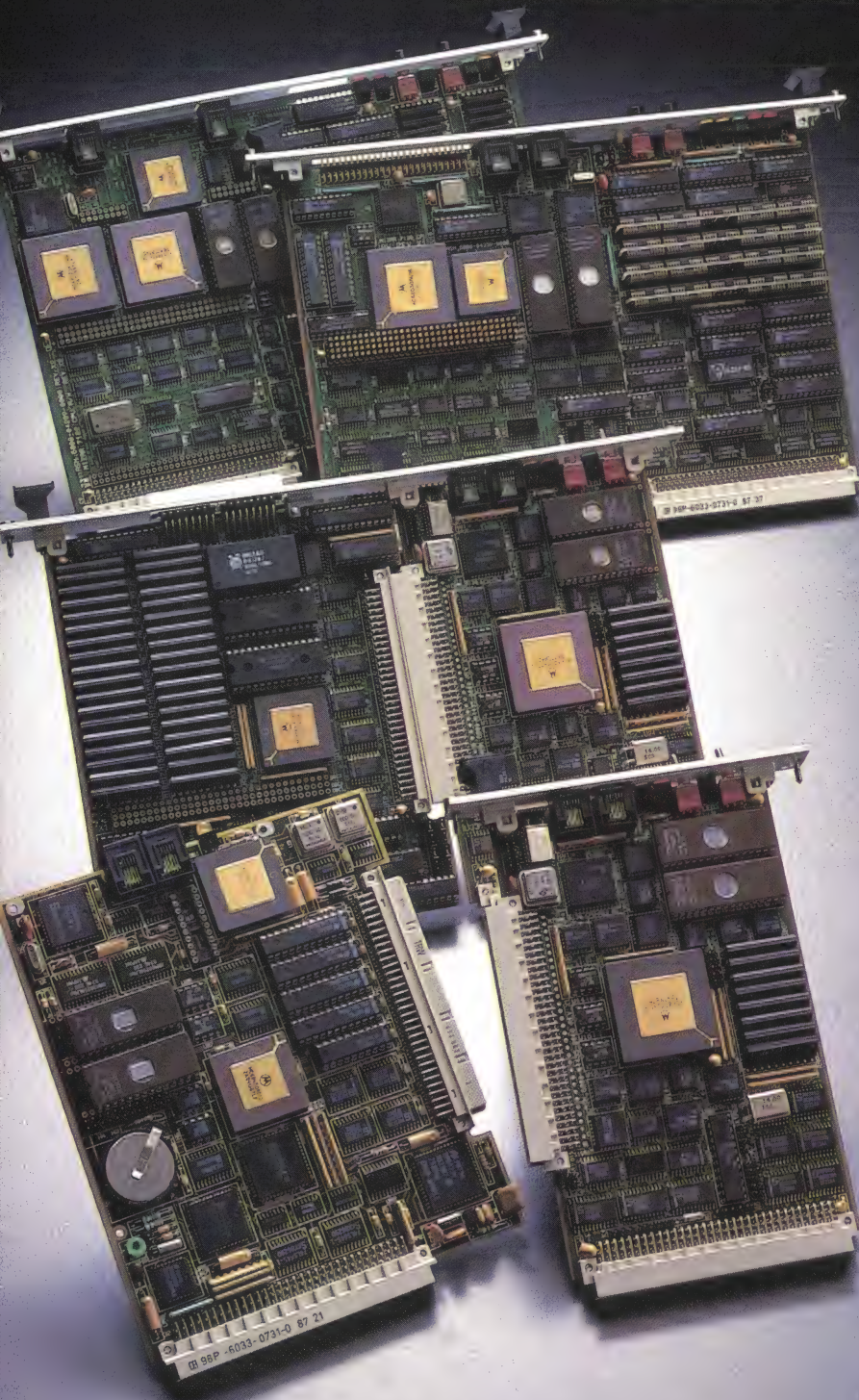
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## **New standards of VME performance.**

Mizar presents a new line of micro-processors for VME-based applications. With powerful Motorola 68020 and 68030 CPUs at up to 30 MHz, and the latest in memory interface and surface mount technology, Mizar provides the performance and functionality your application demands.

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Mizar designed its new processors with the application developer in mind. Mizar's single-height processors are not only excellent computing engines, but through Mizar's MXbus™, become uniquely configurable to meet specific I/O, memory and processing needs. MZ 8100 Series single-height processors can be transformed into double-height solutions with complete single-board functionality and performance. Similarly, the MZ 7100 Series of double-height processors provide all you expect from a single board computer, and can be tailored with easy-to-use plug-in modules. With either solution, you can start development today.

## **Superior memory handling.**

Mizar's engineers have reduced critical wait-states to zero at 16.7, 20 and 25 MHz in many cases. To enhance multiprocessor system performance, Mizar's new on-card memory arbitration logic frees the CPU during time-consuming memory operations across the VMEbus, allowing concurrent local processing. And for more demanding applications, Mizar's 68030 based MZ 7130 even includes cache options.

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CIRCLE NO 125



# NEWS BREAKS

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EDITED BY JOANNE DE OLIVEIRA

## **FIRST 20-GHZ COUNTER FOR VXI BUS IS AVAILABLE**

The Model 2151 microwave counter from Racal-Dana Instruments Inc (Irvine, CA, (714) 549-8999) measures frequencies from 10 Hz to 20 GHz. The counter can resolve a 20-GHz signal to 1 Hz in 1 sec. Besides measuring frequency, the instrument-on-a-card also measures period and frequency ratios between two signals. The counter offers -27-dBm sensitivity at 20 GHz, and it has an operating range of 34 dB. You can use the counter effectively on AM signals with 90% modulation. For signals with high levels of FM, you can use a manual mode to preset the counter within 60 MHz of the center frequency, and the counter will acquire the signal in 20 msec. The instrument fits into a double-width C-size VXI Bus module. It costs \$4585; delivery is 90 days ARO.—Doug Conner

## **CONTENT-ADDRESSABLE MEMORY ACCEPTS 16- OR 48-BIT WORDS**

The Am99C10 content-addressable memory from Advanced Micro Devices (Sunnyvale, CA, (408) 732-2400) operates as a traditional memory in reverse; when you give it a data word, it returns an address. The Am99C10 simultaneously compares each of its 256 memory locations to your data and signals if a match exists. You can also mask any or all bits of your data word, excluding them from comparison, and you can specify memory locations to be ignored. You can set the device to handle 16- or 48-bit words, to read and write information in memory, and to read the address of a successful match. The part comes in a 28-pin DIP or 32-pin PLCC and costs \$42.50 (100).—Richard A Quinnell

## **SPARC-COMPATIBLE COMPUTERS ACCOMMODATE FOUR PROCESSORS**

The Series4 computers from Solbourne Computer Inc (Longmont, CO, (303) 772-3400) employ SPARC (scalable processor architecture)  $\mu$ Ps and execute programs written for Sun 4 computers, including Sun's own diagnostic programs. However, unlike the Sun 4 machines, the Solbourne machines accommodate as many as four SPARC CPUs, so they can execute multiple tasks quickly. Each of the members of the Series4 family includes at least 16M bytes of RAM, a 7-slot VME Bus card cage, an Ethernet LAN controller, two RS-423-A/RS-232C serial ports, a SCSI port for connecting to mass-storage devices, the SunOS Unix operating system, the X Window System and X Window Manager for multiple-window displays, and a C language compiler. A 2-processor Series4/602 with 16M bytes of RAM, a 327M-byte hard-disk drive, and a 150M-byte cartridge tape drive sells for \$51,400. The single-processor Series4/801 server, equipped with 32M bytes of RAM and two SMD drives (providing 1.66G bytes of storage), costs \$75,400. All of the company's computers carry a 1-year warranty.—Steven H Leibson

## **IEEE-488-BUS EXTENDER OPERATES TO 2000M**

The Model 4889 Roadrunner from ICS Electronics Corp (San Jose, CA, (408) 432-9009) allows you to extend your IEEE-488 bus by as much as 500m with coaxial cable or 2000m with fiber-optic cable, without incurring a length-dependent speed reduction. The unit is transparent to all commands, including those from HP-IB- and CS-80-based systems. It communicates at 300k bytes/sec, regardless of the cable length, and adds a 16- $\mu$ sec (max) delay to transfer responses from remote devices. The unit costs \$1695; it will be available in February.—Richard A Quinnell



# NEWS BREAKS

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## **MIXED-SIGNAL SIMULATORS INCLUDE SABER/CADAT**

The DesignSim A&D mixed-signal simulator from NCR (Fort Collins, CO, (800) 334-5454) uses the Saber/Cadat mixed analog/digital simulator with NCR's Product Design Series I and II user interface. The company's Product Design Series also includes two other integrated simulators: The DesignSim A analog simulator is based on Analogy Inc's (Beaverton, OR) Saber simulator, and the DesignSim D digital simulator is built around HHB's (Mahwah, NJ) Cadat. The simulators have full model support for NCR's ASIC cell libraries. DesignSim D will be available in the first quarter of 1989; DesignSim A and DesignSim A&D will follow in the second quarter. —Michael Markowitz

## **C COMPILER INCLUDES SUPPORT FOR FUZZY-LOGIC CONSTRUCTS**

The Fuzzy-C compiler from Togai Infralogic Inc (Irvine, CA, (714) 975-8522) allows software developers to integrate knowledge bases directly in C application programs. Fuzzy logic—computer reasoning that makes inferences on the basis of incomplete or imprecise information—can support applications such as real-time process control and systems diagnostics, and it can be integrated in expert systems. The Fuzzy-C compiler employs a knowledge-representation syntax that allows programmers to develop fuzzy-logic production rules. The compiler also includes an inference engine and a debugger. The company plans to offer such follow-up products as custom VLSI fuzzy-logic processors, in-circuit emulators for fuzzy-logic processors, fuzzy-logic accelerator cards, and seminars and training. An IBM PC-compatible version of the Fuzzy-C compiler costs \$4950, and a version for Apollo, Sony, and Sun workstations costs \$9900. —Maury Wright

## **EVALUATION BOARD SUPPORTS FDDI FIBER-OPTIC LAN**

The Fast evaluation card from AMD (Sunnyvale, CA, (408) 732-2400) plugs into an IBM PC/AT or compatible computer and implements an FDDI (fiber distributed data interface) fiber-optic LAN node. In conjunction with the board, the company offers several software packages, collectively called Supernet support software. The products include FDDIMON, a debugging tool; FDDIDEMO, a menu-driven demonstration program; FDDINET device drivers for MS DOS; and CMT Emulator, a tool for connection-management training. The board incorporates the company's FDDI chip set, which comprises the Am79C81A RAM buffer controller, the Am79C82A data-path controller, the Am79C83A fiber-optic-ring media-access controller, the Am79C84A encoder/decoder (ENDEC), and the Am79C85A ENDEC data separator. The chip set costs \$625 (100). A development kit that includes the Fast card and the company's Supernet support software costs \$6000. —Steven H Leibson

## **ROM PROTECTS CODE FROM COPYING**

If you need to protect your ROM-based code from copying, consider using security ROMs from Macronix (San Jose, CA, (408) 434-1133). The MX23CS1024, MX23CS2048, and MX23CS409 are 1M-, 2M-, and 4M-bit ROMs that operate normally in your system, but can't be read outside the system. The devices come in 150- and 200-nsec speeds; prices range from \$6 (OEM qty) for the 1M-bit device to \$20 for the 4M-bit device. —Richard A Quinnell





# TMC2310 Runs 1024-Point FFT in 0.5ms

Here's the FFT runner you need to win the race. It's the TMC2310 — the first single-chip FFT controller to be this fast and simple to use.

Imagine all of these capabilities on one chip: Arithmetic functions, FFT coefficients ("twiddle factors"), even built-in address generation. That's why the TMC2310 runs forward or inverse transformations, or multiple equal-length FFTs totalling 1024 points, in just 0.5ms. Or a complex radix-2 butterfly in only 100ns. The TMC2310 executes other functions just as quickly, including FIR filtering and vector operations. Even data windowing is included without impact on either performance or price.

Better still, no development system is required. The TMC2310 jumps into

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# NEWS BREAKS: INTERNATIONAL

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## **SYSTEM DMM SUITS MILITARY AND AEROSPACE ATE**

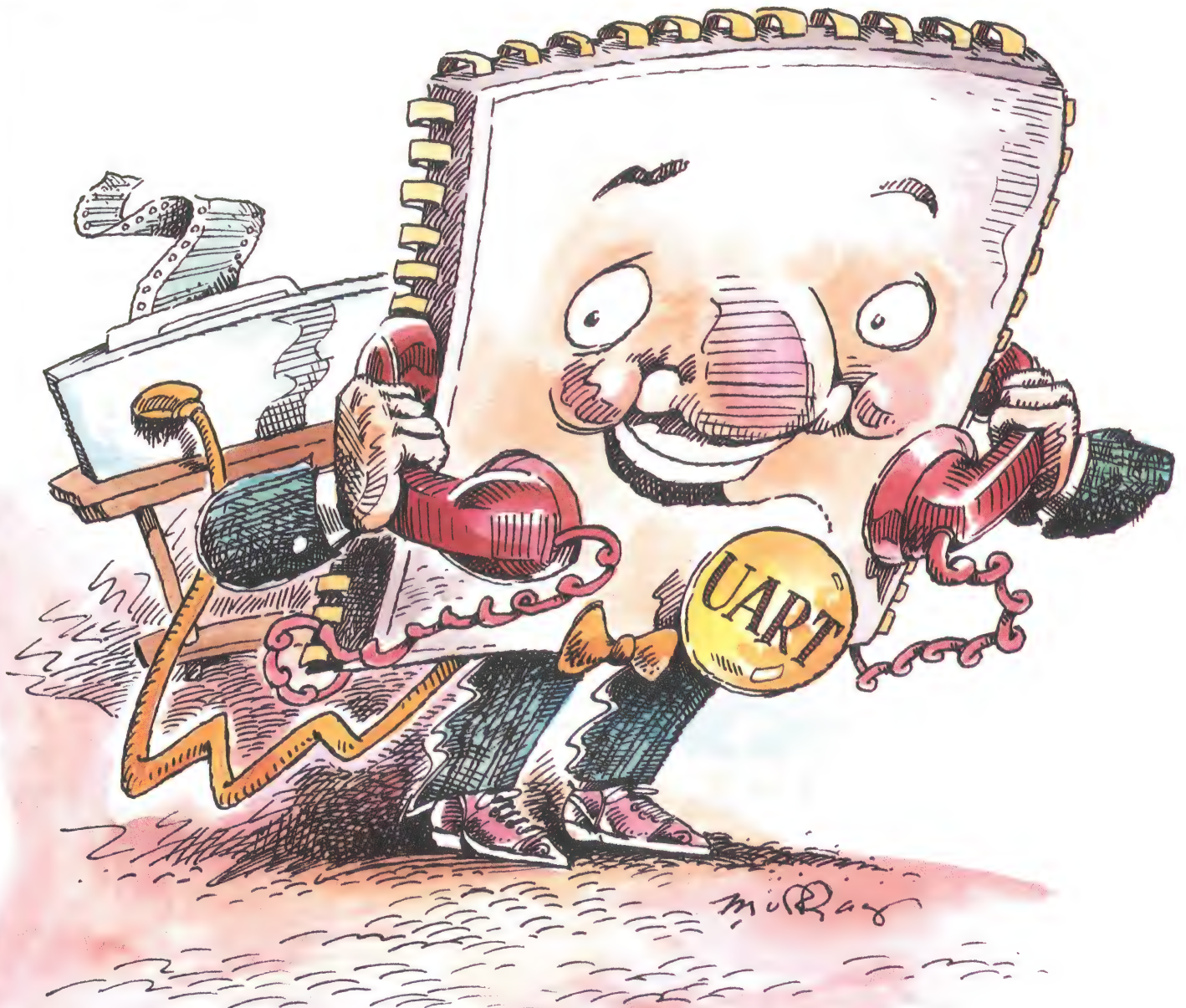
Intended for use in ATE systems, the Model 1271 DMM from Datron Instruments Ltd (Norwich, UK, TLX 975173; in the US: San Diego, CA, (619) 450-9971) combines high measurement accuracy with fast-read-rate capabilities. When it's set for 5 $\frac{1}{2}$ -digit resolution, you can use it to measure dc voltage, dc current, or resistance at 1000 readings/sec, and you can take 6 $\frac{1}{2}$ -digit true-rms ac voltage or current measurements at 20 readings/sec. At reduced read rates, you can extend the DMM's measurement resolution to 8 $\frac{1}{2}$  digits for dc voltage, dc current, and resistance. At 1000 readings/sec, the instrument stores as many as 6000 readings in internal memory. You can then send these readings over the instrument's integral IEEE-488 interface. Alternatively, the DMM can continuously measure an input signal and send it over the IEEE-488 bus at 150 readings/sec. The company heralds the 1271 as the first system DMM to conform fully to the IEEE-488.2 specification, which includes standardized message formats, instrument-status reporting, and common-command-set handling. The DMM is optionally available with the Mate CIIIL bus-command set.

The 1271 has 1-year accuracies of  $\pm 7$  ppm for its 10V dc range and  $\pm 10$  ppm for its 100 $\Omega$  to 100-k $\Omega$  resistance ranges. For ac measurements, you can choose high-accuracy or high-speed ac-converter options with 1-year accuracies (1V to 100V ranges, 1 kHz) of  $\pm 80$  and  $\pm 300$  ppm, respectively. The instrument's high accuracy is due to its internal self-calibration routines. You can calibrate the DMM against external reference standards by using autocalibration procedures controlled either from the front panel or over the IEEE-488 bus. The self-calibration feature lets you virtually eliminate temperature-coefficient effects in the DMM's measurement circuits when you operate the DMM at elevated or reduced temperature. The self-calibration facility also provides the internal reference voltages required for the instrument's comprehensive self-test. A version of the 1271 that has dc-voltage, ac-voltage, and resistance-measurement functions costs \$4985.—Peter Harold

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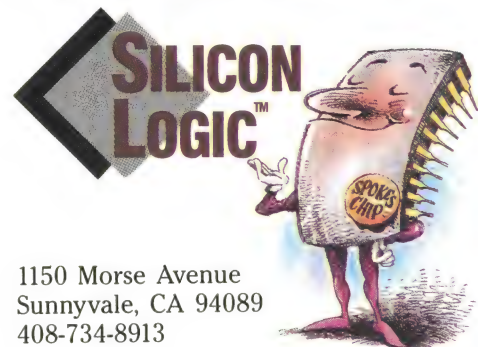
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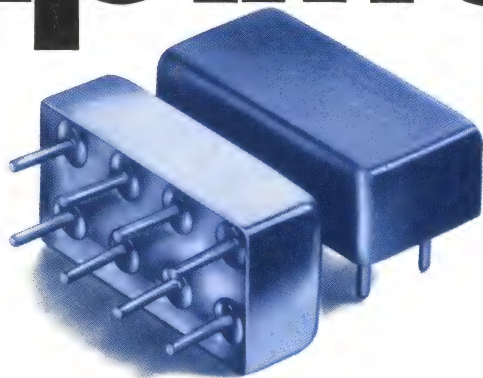
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| Min. Pass Band (MHz) DC to                                          |       |      | 10.7 | 22   | 32 | 48 | 60 | 98  | 140 | 190 | 270 | 400 | 520 | 580 | 700  | 780  | 900  |
| Max. 20dB Stop Frequency (MHz)                                      |       |      | 19   | 32   | 47 | 70 | 90 | 147 | 210 | 290 | 410 | 580 | 750 | 840 | 1000 | 1100 | 1340 |
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| HIGH PASS                                                           | Model       | *HP- | 50  | 100 | 150 | 200 | 250  | 300  | 400  | 500  | 600  | 700  | 800  | 900  | 1000 |
|---------------------------------------------------------------------|-------------|------|-----|-----|-----|-----|------|------|------|------|------|------|------|------|------|
| Pass Band (MHz)                                                     | start, max. |      | 41  | 90  | 133 | 185 | 225  | 290  | 395  | 500  | 600  | 700  | 780  | 910  | 1000 |
|                                                                     | end, min.   |      | 200 | 400 | 600 | 800 | 1200 | 1200 | 1600 | 1600 | 1600 | 1800 | 2000 | 2100 | 2200 |
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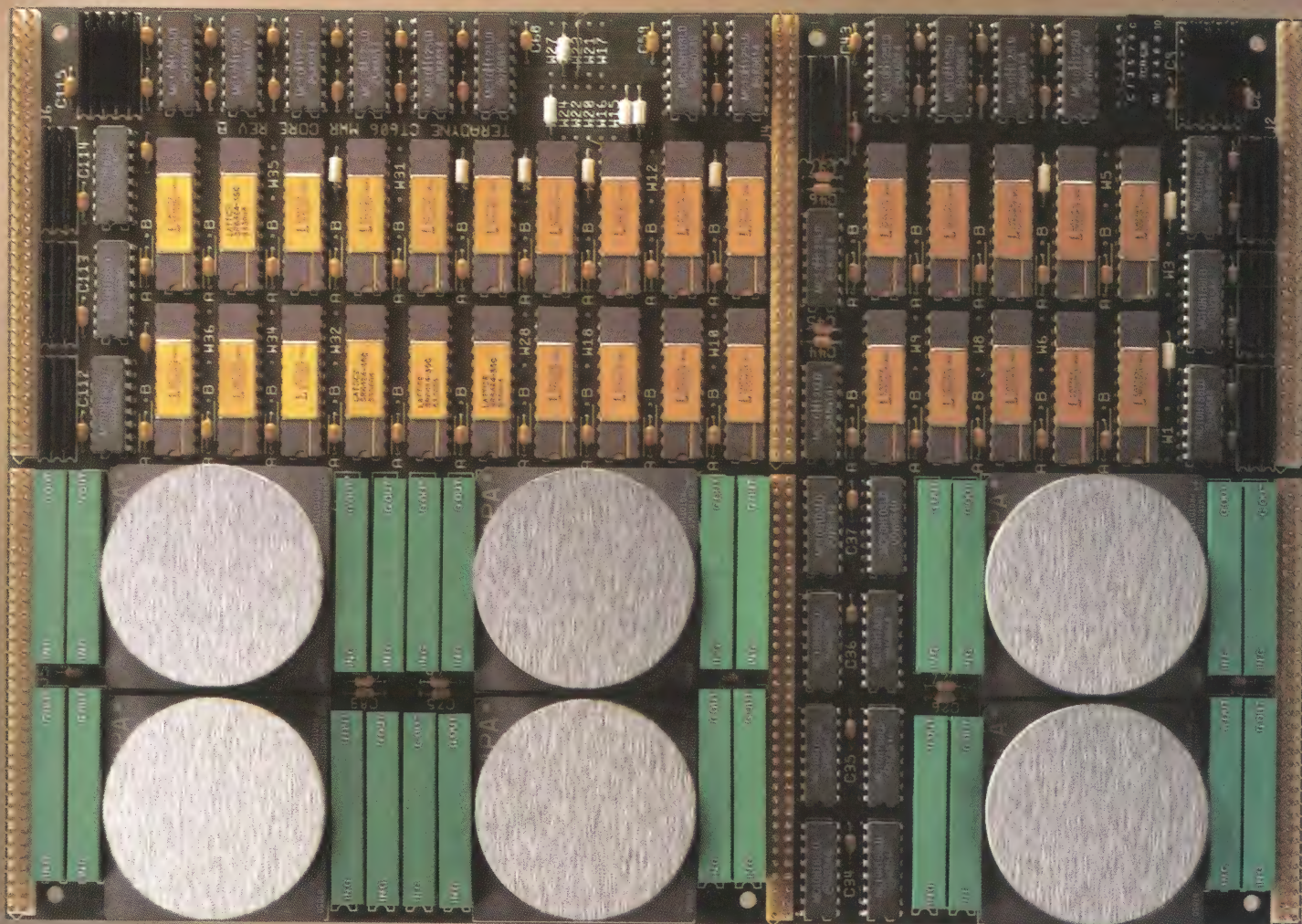
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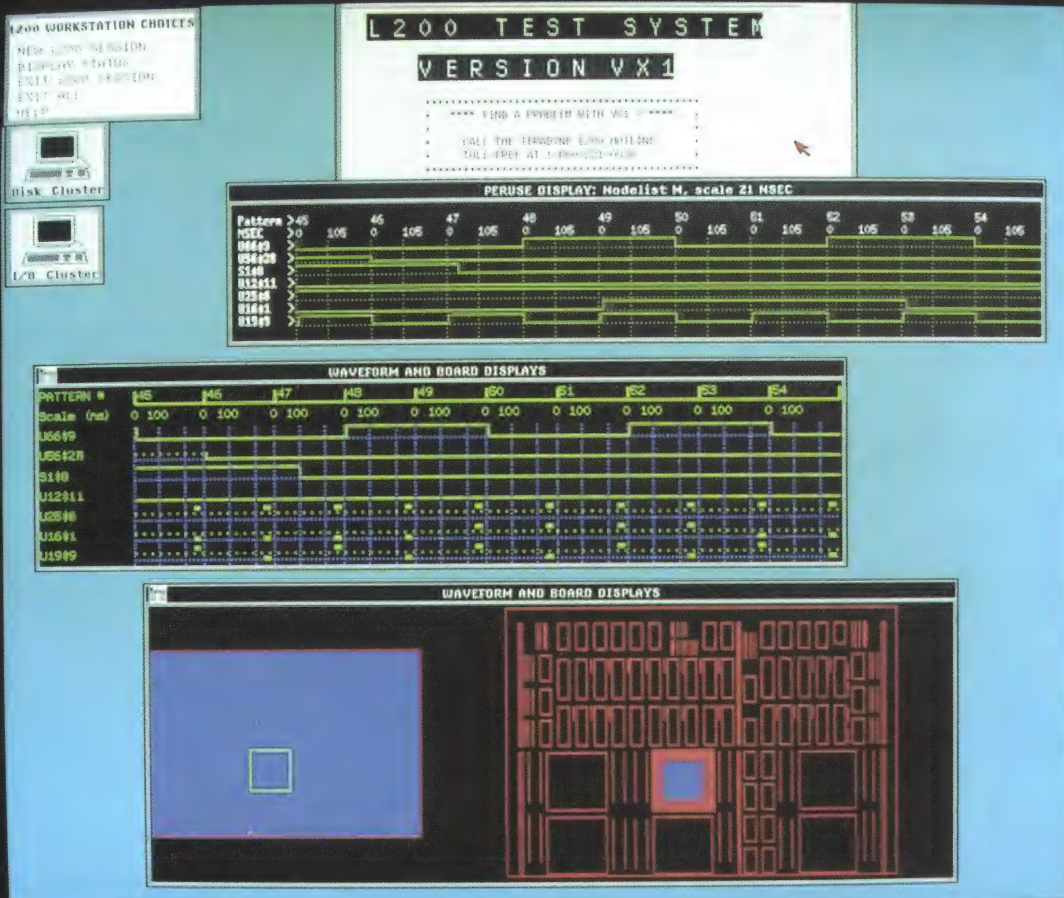
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| L210vx        | 576                  | 10 MHz $\pm 10$ ns  |

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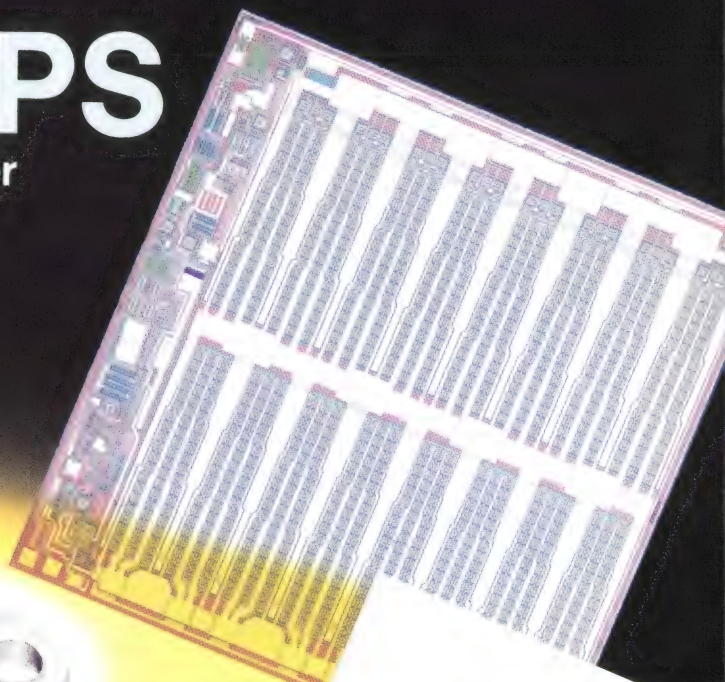
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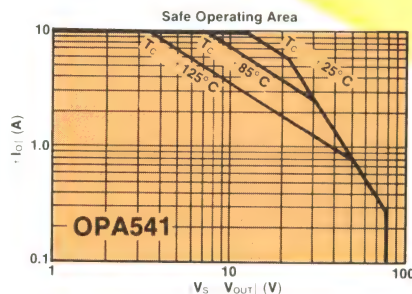
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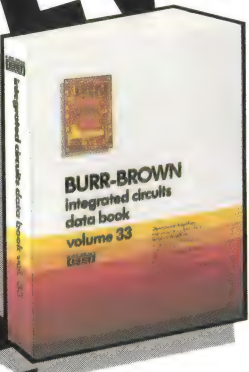
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CIRCLE NO 38

# SIGNALS & NOISE

## More algorithm sources

Looking for sources of algorithms is a common problem faced by many EEs at work. I say this because I went through a situation similar to Alan Clark's (Signals & Noise, EDN, August 4, 1988, pg 31) some years ago. I want to suggest a few publications, books, and sources that are very helpful to both hardware and software engineers.

First, you may find the following publications helpful:

Malick, J D, *BasicA Science & Graphics Handbook*, Simplification Unlimited, Menlo Park, CA.

Schildt, Herbert, C: *The Complete Reference*, Osborne/McGraw-Hill.

Johnson, Nelson, *Advanced Graphics in C*, Osborne/McGraw-Hill.

*Scientific & Engineering Applications with Personal Computers*, John Wiley & Sons.

Also, you could join a computer book club, or have publishers mail you information on their latest publications. Osborne/McGraw-Hill, especially, publishes very good software books. *Byte Magazine*, EDN's Design Ideas sections and supplements, and Microsoft Press are also good sources.

I ensure you that the above sources will provide every algorithm you need for any kind of application (at the very least, the ones Alan Clark mentioned). Some of these publishers also offer the routines on disk for around \$20 to \$30.

Sean Nihalani

President

Suntech Imaging Corp  
Huntington Beach, CA

## Consider alternatives to floating-point math

The following may be of use to Alan Clark:

A reference for transcendental

functions is *Computer Approximations* by J Hart et al, which was reprinted recently by R Krieger Publishing. I have found the book useful for exponentials and logarithms as well as trigonometry. I should also give credit to Phil Koopman Jr for his article "Transcendental Functions" in *Forth Dimensions*, November/December 1987. You can contact the Forth Interest Group at (408) 277-0668 for reprints.

Integer square root routines for the 8086/88 have appeared in *Dr Dobbs' Journal*, April 1983; routines for the 68000 have appeared in many EDN Design Ideas. Conversion from integer to floating point and vice versa is highly dependent on your floating-point format; read Knuth's *The Art of Computer Programming*, Volume 2, chapter 4 to get a handle on this.

My only offering on the graphics front is a pointer to Jack Bresenham, an IBM employee who described the currently acceptable algorithm for straight-line drawing. A review of his algorithm appeared in *Byte*, March 1988. I have an 8080 implementation of a similar algorithm. (The same issue also provides some enlightenment on floating-point topics.)

In closing, I should confirm what you may have suspected—my first language is Forth. Therefore, I must urge you (in an 8-bit environment without math-coprocessor support) to strongly consider alternatives to floating-point arithmetic. Thirty-two-bit integers give you good speed and numbers as high as  $\pm 2$  billion to play with. Fourteen-bit fractions can help in some applications (8192 means 0.5, etc). Rational approximations ( $\pi$  is 355/113) often give results with errors of less than 10 ppb for a 16-bit numerator and denominator.

Bill Hall

Woodhenge Systems  
Deerfield, NH



## True general-purpose algorithms don't exist

I have programmed (for various microprocessors) algorithms for the arithmetic, transcendental, base-conversion, floating-conversion, and ASCII-conversion functions sought by Alan Clark (Signals & Noise, EDN, August 4, 1988, pg 31). I can appreciate his problems, because I have had to do considerable mathematical and processor-hardware research to support my algorithm selections and programming. I have programmed "ordinary" floating-point, conversion, and transcendental function packages, as well as some more exotic things, including memory-filling square roots, long-precision incomplete elliptic integrals, and 64-bit binary logarithms.

I can demonstrate (though I won't do so here) that you must take so very many mathematical considerations and factors into ac-

count to achieve satisfactory accuracy and efficiency in this subject area, that distilling the results into some few "fundamental" and "general-purpose" algorithms is simply not possible. Worse, the complexities can be such that a designer unversed in the subject and attempting to make an uncritical choice of algorithm could produce a very bad result without knowing it, and could subject his firm to liability.

I have found the textbooks and technical papers in this field to be highly illuminating, but these references contain material that requires interpretation and the execution of critical judgment before you apply it. A recent magazine article ("Some assembly required: Floating-point without a coprocessor" by Rick Graham, *Byte*, September 1988, pg 313) is representative of this type of technical material, and might serve as a starting point. Perhaps someone should sponsor a new book,

teaching what is involved and explicitly including the criteria for selecting algorithms.

Some of Alan Clark's needs can be met if his expectations are low-level enough and are sufficiently circumscribed. For example, where an ordinary floating-point package is needed, and when one of the standard binary or decimal floating-point formats is to be used, I could demonstrate (again, not here) that some of the required arithmetic and conversion functions can be flowcharted by inspection, with due care for the cases that arise. The ability to do this flowcharting by inspection is a consequence of the regularity of Arabic number representation. If you require efficiency, however, you might have to tailor that flowchart to best utilize the microprocessor's instruction repertoire.

With regard to square roots and to the trigonometric/transcendental

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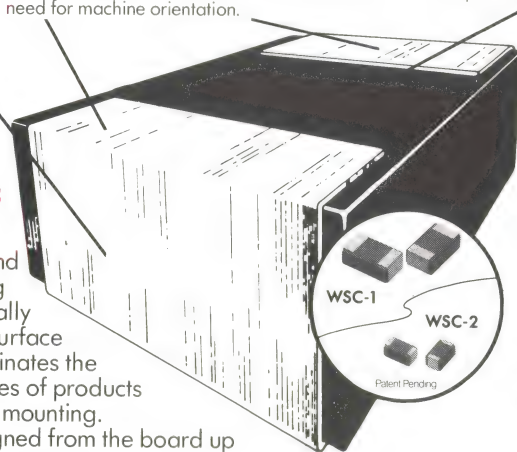
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# SIGNALS & NOISE

functions of an ordinary floating-point package, it will suffice for me to caution those who select algorithms that the subject is not trivial, that even packages from reputable vendors can be unsatisfactory, and that there are dozens of algorithms that can be applied. With regard to graphics, where subjective and aesthetic considerations are very important, similar cautions apply.

Now that the cost of software is understood as being potentially many times the cost of hardware, I could argue that Clark should not even consider applying a microprocessor that is unsupported by a high-level-language compiler and by a sufficient mathematical-function library package. To this argument, I would add that the needs of modern mathematics frequently transcend the capabilities of the ordinary function package that comes with, say, a typical Fortran com-

piler. Clark's designers should, therefore, acquire enough knowledge of the package's capabilities, against the application's needs, to know when to call a consultant.

Pathological cases encountered in applications arise from requirements for speed, program minimization, special hardware and coprocessor support, exactness, monotonicity, symmetry, over/underflow control, and unusual precision. For the analytic and transcendental functions, these pathologies are compounded in the case of complex arguments, accuracy near singularities and cuts, large arguments, asymptotic function evaluation, etc. There's a lot more to be said about these cases. There are some fundamental principles the designer should know. But I would hold out no hope for finding "fundamental" or "general-purpose" algorithms to handle these cases.

*David E Wallis*

*Member of Technical Staff  
Ground Data Systems  
Jet Propulsion Laboratory  
Pasadena, CA*

## YOUR TURN

EDN's Signals and Noise column provides a forum for readers to express their opinions on issues raised in the magazine's articles or on any topic that affects the engineering industry. Send your letters to the Signals and Noise Editor, 275 Washington St, Newton, MA 02158. We welcome all comments, pro or con. All letters must be signed, but we will withhold your name upon request. We reserve the right to edit letters for space and clarity.

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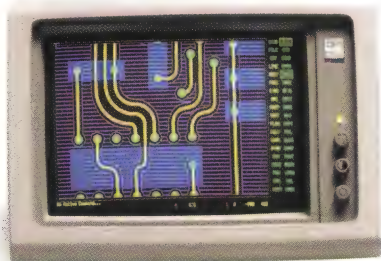


# The P-CAD Software That Made This Famous Laptop Computer Is Now Made To Fit Your Budget.

When Zenith Data Systems needed to pack power into their laptop computers they turned to P-CAD®'s Master Designer™ printed circuit board software.

Why? Because only Master Designer was powerful enough to meet their tough requirements.

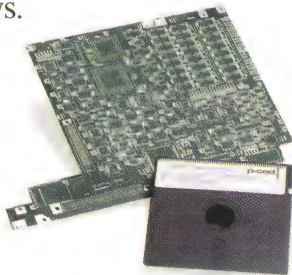
Today, the same software used by Zenith Data Systems and over 10,000 others is available to PCB designers everywhere. Modular software that costs about half what you'd expect.



For starters, Master Designer's schematic capture and interactive layout lets you design using the latest through-hole and surface mount technologies.

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And that'll help you justify even more modules. Such as rip-up and re-try routing. Thermal analysis. Gerber previewing and editing. Analog circuit simulation. A DXF interface for mechanical design and technical publications.

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No wonder over 100,000 boards a year are designed with P-CAD software.

For more information call 800-523-5207. In California, dial 800-628-8748. Or send us this coupon and we'll mail you a free preview copy of our PCB Design User's Guide. Complete with a CAD Buyers Guide to help you select the CAD system that's right for you.

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CIRCLE NO 79





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D-8510 Fürth

USA: Siemens Semiconductor Group, 2191 Laurelwood Road, Santa Clara, CA 95054, mentioning "ISDN-Chips".

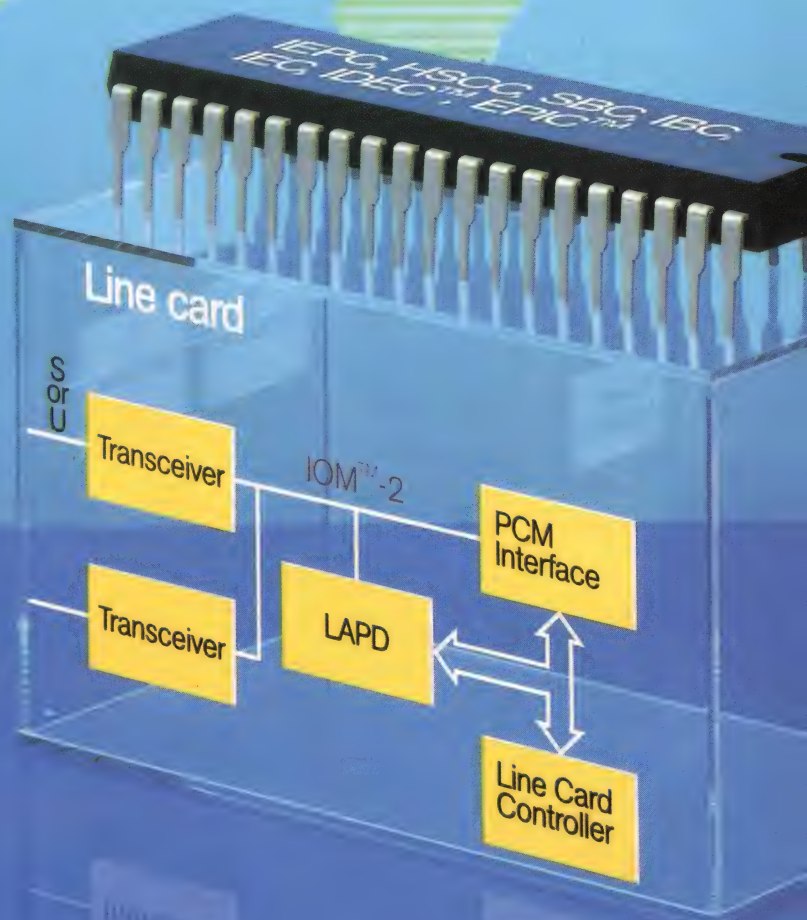
# TopTech Components from Siemens: the key to digital communication systems

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# We Supply Solutions Every Step of the Way





## *From single ICs to board-level development, Oki's systems approach gives you a competitive edge*

Oki Semiconductor offers you a unique array of products, leading-edge technologies, and comprehensive support services. But what really sets us apart is our unique way of applying them. We call it *System Technologies for Customer Solutions*.

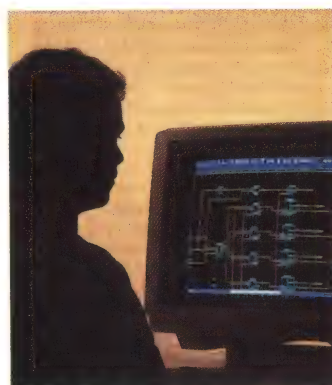
### ***Oki systems thinking***

Rather than just taking your order as other suppliers might do, we join with you as a partner and work to understand your product concept as a whole, before determining its component technologies. Then to meet your goals, we draw on a tremendous range of expertise and worldwide resources others simply cannot match.

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As the only company that can deliver standard IC, ASIC, packaging, and value-added capabilities *from a single source*, we can uncover options and alternatives at many levels of system development and fabrication—opportunities others would not perceive. So we can assist you with everything from single ICs to value-added products, at any stage you require.

The result of this integrated, single-source approach is a solution that's precisely tailored to your needs. A solution that can help you achieve real competitive advantages—by speeding product development, getting you to market faster, lowering costs substantially, enhancing your product with new features, or making production more efficient.



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as highly capable people who help you make the most of our resources. If you'd like to gain the kind of competitive edge Oki customers already enjoy, call us today or complete and mail the coupon below. And find out how Oki's unique blend of partnership and systems thinking can make a real difference for you.

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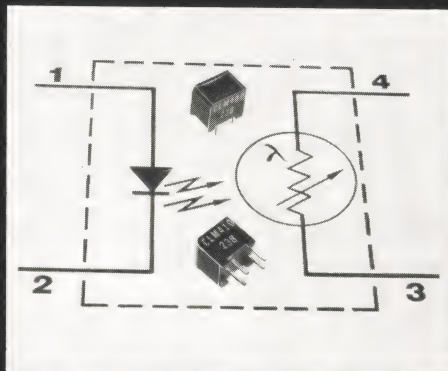
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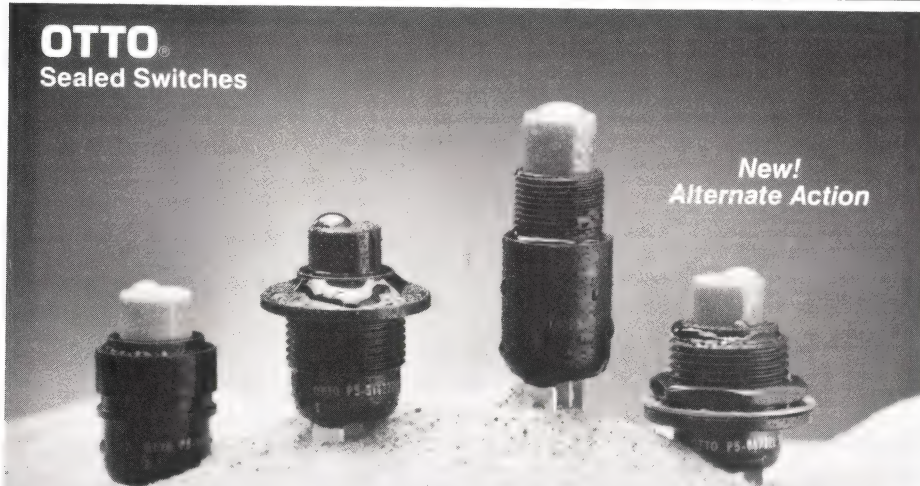
For the optimum solution to each of your individual "light" problems, call 914-664-6602 or FAX 914-664-6449 or write Clairex®, 560 South Third Avenue, Mount Vernon, New York 10550.

## CLAIREX ELECTRONICS

A Division of Clairex Corporation

CIRCLE NO 3

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## Dry Desert to Wet World

Survival! That's what you can expect from OTTO precision snap-action pushbutton switches. Sealed to survive the rigors of industrial, commercial and military applications, these switches are available in momentary and alternate (push-on, push-off)

action, miniature and subminiature sizes, choice of front panel appearance and button colors.

Sealed against dirt and water. Electrical ratings from computer level to 10 Amperes. Contact resistance < .025 ohms.

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CIRCLE NO 4

## CALENDAR

**The 1989 Optical Disk Systems Conference: From the Mail Room to the Board Room**, Phoenix, AZ. CAP International Inc, 1 Longwater Circle, Norwell, MA 02061. (617) 982-9500. January 23 to 25.

**ATE & Instrumentation Conference West**, Anaheim, CA. MG Expositions Group, 1050 Commonwealth Ave, Boston, MA 02215. (800) 223-7126; in MA, (617) 232-3976. January 23 to 26.

**Winter 1989 Unix Technical Conference**, San Diego, CA. Usenix Conference Office, Box 385, Sunset Beach, CA 90742. (213) 592-1381. January 30 to February 3.

**Electromagnetic Interference—Characteristics and Control** (seminar), Center for Continuing Engineering Education, University of Wisconsin-Milwaukee, 929 N Sixth St, Milwaukee, WI 53203. (414) 227-3120. January 31 to February 2.

**Power Electronic Conference '89**, Santa Clara, CA. Bob Mignarri, Conference Management Corp, 200 Connecticut Ave, Norwalk, CT 06854. (203) 852-0500. February 7 to 9.

**Software Development '89**, San Francisco, CA. Miller Freeman Publications, 500 Howard St, San Francisco, CA 94105. (415) 995-2471. February 14 to 17.

**Power Supply Design Seminar**, Tampa, Orlando, and Fort Lauderdale, FL; Huntsville, AL. Unitrode Corp, 580 Pleasant St, Watertown, MA 02172. (617) 926-0404. February 21 to 24.

**Semiconductor User and Applications Industry Conference**, San Francisco, CA. Dataquest, 1290 Ridder Park Dr, San Jose, CA 95131. (800) 624-3282. February 27 to 28.



# At Last, a *Truly* Industrial PC AT System for the OEM

Easy to mount Eurocard hardware with optional power supply. Can be rack mounted or bolted into any embedded system.

Three side mechanical bond into the card cage, yet easy to access for simplified maintenance.

100% compatible EGA color display and AT keyboard interface.

Genuine Intel 80286, 10 MHz CPU, for true AT performance.

512K of fast access RAM, Clock/calendar, dual communication port and optional 80287 Arithmetic Unit on a very high density, two layer PC board.

Compact single height Eurocard board format (100 x 160 mm) that doesn't flex or bend and withstands the toughest shock and vibrations.

Full 32-bit expansion bus for easy system expansion and customization with up to 20 slots.

96-pin DIN pin-in-socket for a gas-tight connection guaranteed to last forever.

Unprecedented selection of inexpensive I/O functions, from the simplest parallel and serial I/O, to high performance networking, X.25, motor control and imaging.

Introducing the first PC AT system originally designed to be embedded into your machinery or instrumentation.

With the GESPAC AT system, "ruggedized PC" no longer describes a desk top PC in a stronger black box. Rather it is an architecture made to last by design, with such features as small and robust board format, and ultra-reliable pin-in-socket DIN connector.

What's more, the GESPAC System is built for performance with Intel's original 80286 processor and 80287 Arithmetic Unit — In fact this system is the most compact implementation of the 286 in the market today.

The powerful G-64 bus interface lets you customize your AT system with any of the 200-plus system components available from GESPAC, to match virtually any system requirement.

Take advantage of GESPAC's 10 years of experience in serving the OEM marketplace. Call today to receive your free data sheet and our new 116 page catalog of board level microsystem products.



**Call Toll Free 1-800-4-GESPAC or call (602) 962-5559.**

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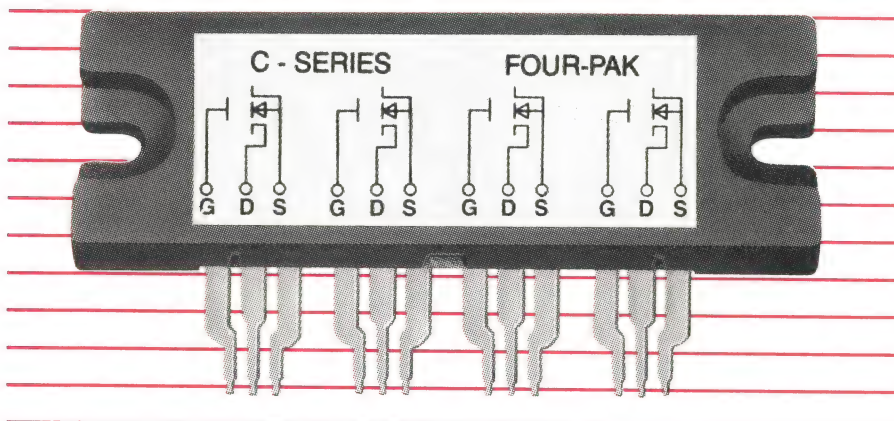


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# MOSFET

- SPECIFICALLY DESIGNED WITH LOW CIRCUIT INDUCTANCE FOR HIGH SPEED SWITCHING TO 5 N.S.
- CONSTRUCTION YIELDS 2500 VOLTS(RMS) OF ELECTRICAL ISOLATION TO THE HEATSINK
- LOW THERMAL RESISTANCE JUNCTION TO CASE
- PACKAGE HAS PRINTED CIRCUIT PINS (OPTIONAL 90° BEND)



| V <sub>DS</sub><br>Drain-Source<br>Voltage<br>(volts) | I <sub>D</sub><br>Drain<br>Current<br>(amps) | R <sub>DS</sub><br>Drain-Source<br>Max. Resist.<br>(ohms) | GENTRON<br>PART NO. |
|-------------------------------------------------------|----------------------------------------------|-----------------------------------------------------------|---------------------|
| 100                                                   | 27                                           | 0.09                                                      | CM07                |
| 200                                                   | 18                                           | 0.18                                                      | CM05                |
| 400                                                   | 10                                           | 0.55                                                      | CM03                |
| 500                                                   | 8                                            | 0.85                                                      | CM01                |

To find out more about Gentron's transistor series, contact:



**Gentron Corporation**

6667 North Sidney Place, Milwaukee, WI 53209  
(414) 351-1660 Telex: 26881

CIRCLE NO 5

## DID YOU KNOW?

Half of all EDN's  
articles are staff-written.

# EDN

## CALENDAR

**Compcon Spring '89** (34th IEEE Computer Society International Conference), San Francisco, CA. Kenichi Miura, Fujitsu America, 3055 Orchard Dr, San Jose, CA 95134. (408) 432-1300. February 27 to March 3.

**Commercially Available Reduced-Instruction-Set Computer Processors** (seminar), Anaheim, CA. Dr Amnon Aliphas, DSP Associates, 18 Peregrine Rd, Newton, MA 02159. (617) 964-3817. March 1 to 3.

**Systems Engineering for Integrated Hardware/Software Applications** (short course), Los Angeles, CA. John Valenti, Integrated Computer Systems, Box 3614, Culver City, CA 90231. (800) 421-8166; in CA, (213) 417-8888. March 7 to 10.

**The Executive Forum on Supercomputing**, San Jose, CA. Pat Westly, Westly Enterprises, 3697 S Court, Palo Alto, CA 94306. (415) 494-7115. March 9 to 10.

**APEC '89 (IEEE Applied Power Electronics Conference and Exposition)**, Baltimore, MD. Trey Burns, Data General Corp, 4400 Computer Dr, E213, Westboro, MA 01580. (508) 870-9182. March 13 to 17.

**C Programming Workshop**, Seattle, WA. Specialized Systems Consultants Inc, Box 55549, Seattle, WA 98155. (206) 527-3385. March 13 to 17.

**Modern Electronic Packaging** (seminar), San Diego, CA. Technology Seminars Inc, Box 487, Lutherville, MD 21093. (301) 269-4102. March 20 to 22.

**DCA Forecast to Industry** (seminar), Tyson Corner, VA. Janie Herring, AFCEA NOVA Chapter, The BDM Corp, 7915 Jones Branch Dr, McLean, VA 22101. (703) 848-6944. March 27 to 28.



# HP TURNS 030.



It couldn't have happened to a better company.

This past June, Hewlett Packard became the first major U.S. computer manufacturer to introduce a workstation system based on Motorola's 68030 32-bit microprocessor.

As expected, it's turned out to be quite a system. The HP 9000 Model 360, in fact, reaches processing speeds of up to 5 MIPS at 25 MHz. And the new Model 370 hits over 8 MIPS at 33 MHz.

Largely due to Motorola's 030. After all, it delivers more performance than any other

conventional microprocessor on the market today, and even outruns a number of RISC\* processors. Plus it offers firsts like on-chip data and instruction

caches, parallel architecture and unique DRAM interface.

That's why if you're planning a high-performance system, plan on talking to us first. For free benchmarks and more information, contact your Motorola sales office.

After all, one great turn deserves another.



**MOTOROLA**

\*Reduced Instruction Set Computer.

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Now, what about  
the other 95%  
of your design?



## Signetics NE5212 Dream Head

## Signetics 27HS64 Marks Entry Into CMOS EPROM Market

SUNNYVALE, CA. May XX, 1988—Signetics today announced its entry into the High Performance segment of the CMOS EPROM market with the unveiling of an 8K x 8 device that offers bipolar speed and CMOS low-power performance at competitive pricing.

"Our part is one of the fastest of its kind on the market," said Jerry Leeder, vice president and general manager of the Application Specific Product division for Signetics. "And Signetics has the added advantage of being the only high-volume producer to introduce a CMOS device."

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## Signetics Single Port 1Mbit DRAM Controller Handles 40ns Access DRAMs

SUNNYVALE, CA. May 23, 1988—Signetics announced today a new series of 1Mbit dynamic RAM controllers that offer synchronous single- and dual-port operation at 100MHz refresh address generation for DRAMs up to 40ns.

The 74F1764 and 74F1765 are

recent additions to Signetics' FAST logic family, and are extensions of the 256Kbit versions, the 74F1764 and 74F1765. The 74F1764 differs from the 74F1765 only in that it has an on-chip input address latch—a useful feature for systems that employ unlatched or multiplexed address and data buses.

## Signetics Expands ACL Family With 47 New Functions

SUNNYVALE, CA. Signetics announced today the addition of 47 new Advanced CMOS Array and t-

raising the total number of functions from 10 to 57, making it the most available.

The new functions provide a response to the firm's customers' needs for the complete ACL design. Include multiple registers, counters and various new parts, such as receivers, buffers and inverters, have been specifically selected to satisfy a growing need for high-speed bus interface functions.

## Signetics' Ultra-Fast PAL-Type Devices Challenge Industry Speed

## Signetics 74F786 For Metastable— Arbitration

SUNNYVALE, CA. Signetics announced today a new high-speed Array and t- is an asynchronous designed for high-speed applications. The priority of arbitration is determined on a first-come-first-served basis. The priority "Bus Grant" outputs are available to indicate which one of the request inputs is served by the arbitration logic. All "Bus Grant" outputs are available by a common enable (EN) input. In order to generate a bus request signal, a separate 4 input AND gate is provided. This may also be used as an independent AND gate.

## SIGNETICS ENTERS EPROM MARKET AS AN EXCLUSIVE SOURCE FOR THE INT Signetics Unveils Third- Generation Programmable Logic Architecture

SUNNYVALE, CA. Signetics today announced its entry into the EPROM market with the unveiling of a single chip, the S87C51. The device is a direct replacement for Intel 80C51 microcontroller.

SUNNYVALE, CA. November 17, 1986—Signetics today announced its first Programmable Macro Logic (PML) device, the PLHS501 Random Unit. Fully supported by Signetics' advanced PC-based AMAZE design automation software, the PLHS501 marks a major milestone in the evolution of Programmable Logic Devices (PLDs) because it combines the high performance levels expected by users of today's PLDs with substantially greater equivalent logic densities than previously available.

The PLHS501 is a flexible, high-density, high-speed "gate bucket" that provides users with a high pin count and an extremely flexible network of internal foldback paths. It is ideal for implementing any level of logic functions utilizing DeMorgan's

# We've got the guts!

It takes more than a microprocessor to improve product performance.

At Signetics, we haven't developed proprietary MPUs. Instead we've concentrated on the other 95% of your system. We call it "the guts."

That's why we're known as your dependable, world-wide supplier of quality ICs. Producers of devices that are processed with leading-edge technology and supported with customer-oriented service.

We provide everything essential to the total performance of your design. And we make it easy for you to get it. From one vendor. In less time. With less paperwork. For less cost.

We're Signetics. We've got the guts! Make us prove it. Call (800) 227-1817, ext. 982 and ask for our new capabilities brochure.

One standard. 0 defects.

# Signetics

a division of North American Philips Corporation



# PHILIPS



Whether it's a question of speed, bandwidth, power consumption or cost, our family of 8-bit A/D flash converters has the answer.

For example, if you need a monolithic high speed, ECL-compatible converter, there's our AD770 or AD9002.

The AD770 is our fastest ECL-compatible 8-bit converter, with a guaranteed sample rate of 200MSPS. And its 250MHz full power bandwidth and SNR performance with high frequency input signals can't be beaten. The AD770 is available in commercial and extended temperature range versions.

The AD9002 has a guaranteed sample rate of 125MSPS – yet its nominal power dissipation is a mere 750mW – and it operates from a single –5.2V power supply. The AD9002 is also available with MIL-STD-883 processing, making it ideal for a wide range of applications.

On the other hand, if it's a TTL-compatible 8-bit flash converter you need, there's our AD9012 or AD9048.

The AD9012 is the industry's fastest TTL-compatible converter, with a guaranteed sampling rate nearly twice that of its



## ECL COMPATIBLE



### AD770

- High Bandwidth,  
ECL Compatible, 200MSPS
- 400MHz Small-Signal Bandwidth
- 19pF Input Capacitance
- Bipolar or Unipolar Input
- +5V/-5.2V Power Supplies

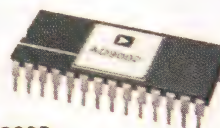
The AD770 200MSPS A/D Converter uses an advanced VLSI bipolar process and a proprietary design to achieve new levels of performance in sampling rates and signal bandwidths for flash converters. Full power bandwidth is 250MHz.

The AD770 is ideal for high performance digital oscilloscope, radar, communications and electronic warfare systems. High input bandwidth permits undersampling of high frequency band-limited signals.

Multistage comparator design reduces the probability of errors due to metastable states or insufficient gain; decoding logic further reduces errors with a two-stage error-correcting architecture.

All inputs and outputs are ECL compatible, and analog inputs can be either bipolar or unipolar signals with up to 4V range. High accuracy and minimum temperature drift are preserved with end point reference Force and Sense connections.

There are three grades available. JD and KD grades are specified over a 0 to +70°C range; the SD grade is specified for temperatures from –55°C to +125°C. All standard grades are packaged in 40-pin ceramic DIPs; contact the factory for other package options.



### AD9002

- Low Power,  
ECL Compatible, 125MSPS
- 160MHz Analog Input Bandwidth
- 17pF Input Capacitance
- 750mW Power Dissipation
- Single –5.2V Power Supply

Designs for radar, digital oscilloscopes, ATE systems, electronic warfare, communications/signal intelligence systems and a wide variety of other applications can be made easier with the AD9002 High Speed Monolithic A/D Converter.

An overflow bit indicating overrange signals can also be used to "stack" two AD9002 units to get 9-bit resolution of the digitized signal.

Input capacitance is typically 17pF and only 22pF maximum, simplifying the choice of a driving amplifier. Cooling requirements and power supply problems are also eased because of the low 750mW dissipation of the AD9002.

Two grades are available; one has 0.5LSB linearity, and the other has 0.75LSB linearity. Both versions are offered for operation from –25°C to +85°C packaged as 28-pin DIPs or 28-pin PLCCs. Military temperature range devices of –55°C to +125°C are available as ceramic DIP and LCC packages; they are compliant to MIL-STD-883 requirements.

# FOR THE WHOLE STORY DO SOME SP



nearest competitor. Plus the AD9012 offers excellent ac performance, low power operation and low input capacitance.

The AD9048 is an improved version of an industry-standard 8-bit TTL-compatible A/D converter, with the highest sampling rate, widest bandwidth, lowest input capacitance and lowest power. And the AD9048, as well as the AD9012, is available to MIL-STD-883.

There's no question about it – high performance characteristics are traits in our family of 8-bit A/D flash converters. So no matter what your requirement is for 8-bit analog-to-digital conversion, we have the solution.

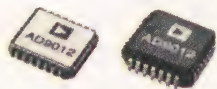
If you want more information in a flash on our 8-bit flash converters, call your nearest Analog Devices sales office or our applications engineers. Answers for the AD770 are at (617) 935-5565. For the AD9002, AD9012 and AD9048, call (919) 668-9511.



Analog Devices, Inc., One Technology Way, P.O. Box 9106, Norwood, MA 02062-9106; Headquarters: (617) 329-4700; California: (714) 641-9391, (619) 268-4621, (408) 559-2037; Colorado: (719) 590-9952; Maryland: (301) 992-1994; Ohio: (614) 764-8795; Pennsylvania: (215) 643-7790; Texas: (214) 231-5094; Washington: (206) 575-6344; Austria: (222) 885504; Belgium: (3) 237 1672; Denmark: (2) 845800; France (1) 4687-34-11; Holland: (1620) 81500; Israel: (052) 911415; Italy: (2) 6883831; Japan: (3) 263-6826; Sweden: (8) 282740; Switzerland: (22) 31 57 60; United Kingdom: (932) 232222; West Germany: (89) 570050.

## 8-Bit Flash Converters

### TTL COMPATIBLE



#### AD9012

- Low Power, Wide Bandwidth, TTL Compatible, 75MSPS
- 160MHz Input Bandwidth
- 16pF Typical Input Capacitance
- Power Dissipation < 1W
- Minimum 46dB SNR

The AD9012 is a TTL compatible A/D converter fabricated in an advanced bipolar process which makes it possible to operate at typical conversion speeds up to 100MSPS.

For commercial and industrial applications, the AD9012 is an excellent choice for professional video, instrumentation, digital radio and PC-based video digitizing equipment.

In military applications, the requirement for mil-qualified devices can be met with MIL-STD-883 units in electronic countermeasures, missile guidance, radar, radar warning and other military systems equipment.

The AD9012 is available in two grades: one has 0.5LSB linearity, and the other has 0.75LSB linearity. Both operate from -25°C to +85°C and are packaged as 28-pin DIPs or 28-pin PLCCs. Military temperature range devices of -55°C to +125°C are available as ceramic DIP and LCC packages.



#### AD9048

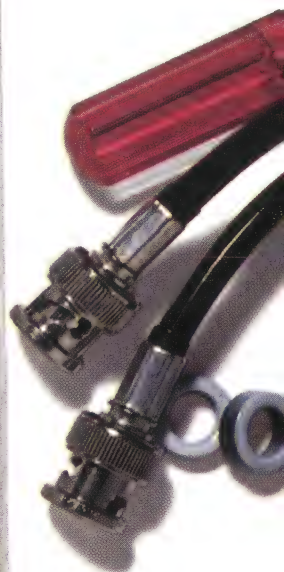
- Low Power, Low Cost, TTL Compatible, 35MSPS
- 15MHz Typical Bandwidth
- Input Capacitance Typically 16pF
- 550mW Power Dissipation
- Industry-Standard Pinouts

As its name implies, the monolithic AD9048 Video A/D Converter is an ideal choice for real-time conversion of video signals.

Its full power bandwidth is typically 15MHz, with no missing codes, and is a guaranteed minimum of 10MHz.

Low power dissipation of 550mW typical makes the AD9048 adaptable and attractive for a broad range of applications. In addition to professional video systems and video imaging, it is an excellent choice for electro-optics, digital radio and electronic warfare systems, among others.

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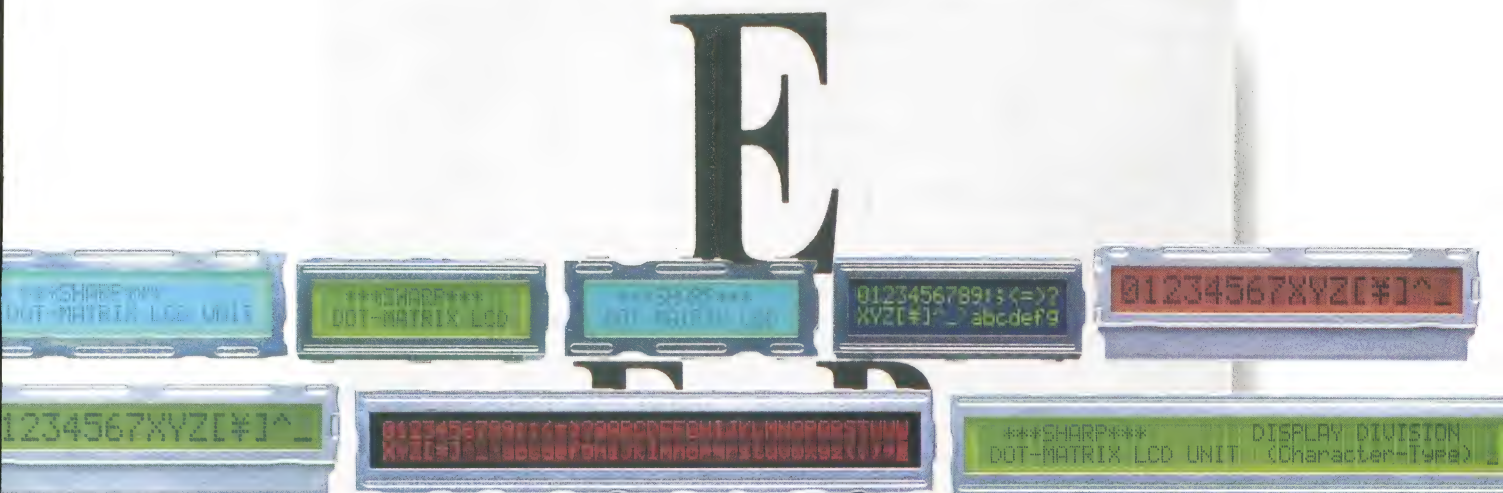
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# EDITORIAL

## Watch your language



I should say from the start that every word of this editorial is copyrighted. If you dare to use one word of it, you may get sued.

Of course, that's a ridiculous position; a copyright doesn't cover each word, only the expression of ideas. If you're a programmer, however, the distinction between individual words and ideas blurs. So watch your language.

Recently, Ashton-Tate, the developers of the popular dBase line of programs, filed suit against two other software manufacturers. Ashton-Tate seeks to keep the other companies from using the dBase language's commands and syntax as well as the structure of dBase programs. In fact, Ashton-Tate claims that it owns the dBase language and no one else may use it.

Although the courts have tackled the issue of a program's "look and feel," they have yet to address who—if anyone—owns a language. When it comes to the dBase language, that issue will be difficult to sort out, because many companies have enhanced the language and have adopted other companies' enhancements, too. You'll need a map to follow the Ashton-Tate case if it ever goes to trial.

It's a bad idea to draw boundaries around a language and claim it as your own. It's difficult to imagine the damage that might have been done if Dartmouth College had claimed ownership of the Basic language, which was developed there in the 60s. I doubt that we'd have had the explosive growth in the small-computer industry that we saw in the late 70s and early 80s. For example, if Dartmouth had claimed ownership of the IF... THEN... ELSE statement, we'd now have to seek alternate implementations if we wanted to develop our own version of Basic. Perhaps WHEN... DO... OTHERWISE would do the trick.

Instead of closing languages to outside innovations and enhancements by assigning ownership to one company or person, we should strive to keep them open. Companies such as Ashton-Tate will complain that opening a language to everyone robs them of a return on their R&D investments. That might appear to be true, but even when a language results from a commercial venture rather than from government or academic research, openness benefits everyone. Companies should spend money keeping ahead of the competition, not suing it.

Open languages breed competition, and competition yields better products and satisfied customers—for both the originators and the enhancers. Except for operating systems, which are tied closely to computer architectures, I can't think of any widespread and successful proprietary languages. The most widespread and successful languages—such as Pascal, Basic, and Fortran—are all open and ready for your extensions and adaptations. Even in the OS realm, many companies offer add-on and enhancement products.

I don't advocate letting programmers plagiarize the instruction-by-instruction implementation of a language's commands and statements. But in the case of a language's actual words, commands, and syntax, it should be a free-for-all. Modern languages wouldn't be very far along today if everyone who added a word copyrighted it and strove to protect the copyright. Computer languages should be open, too.



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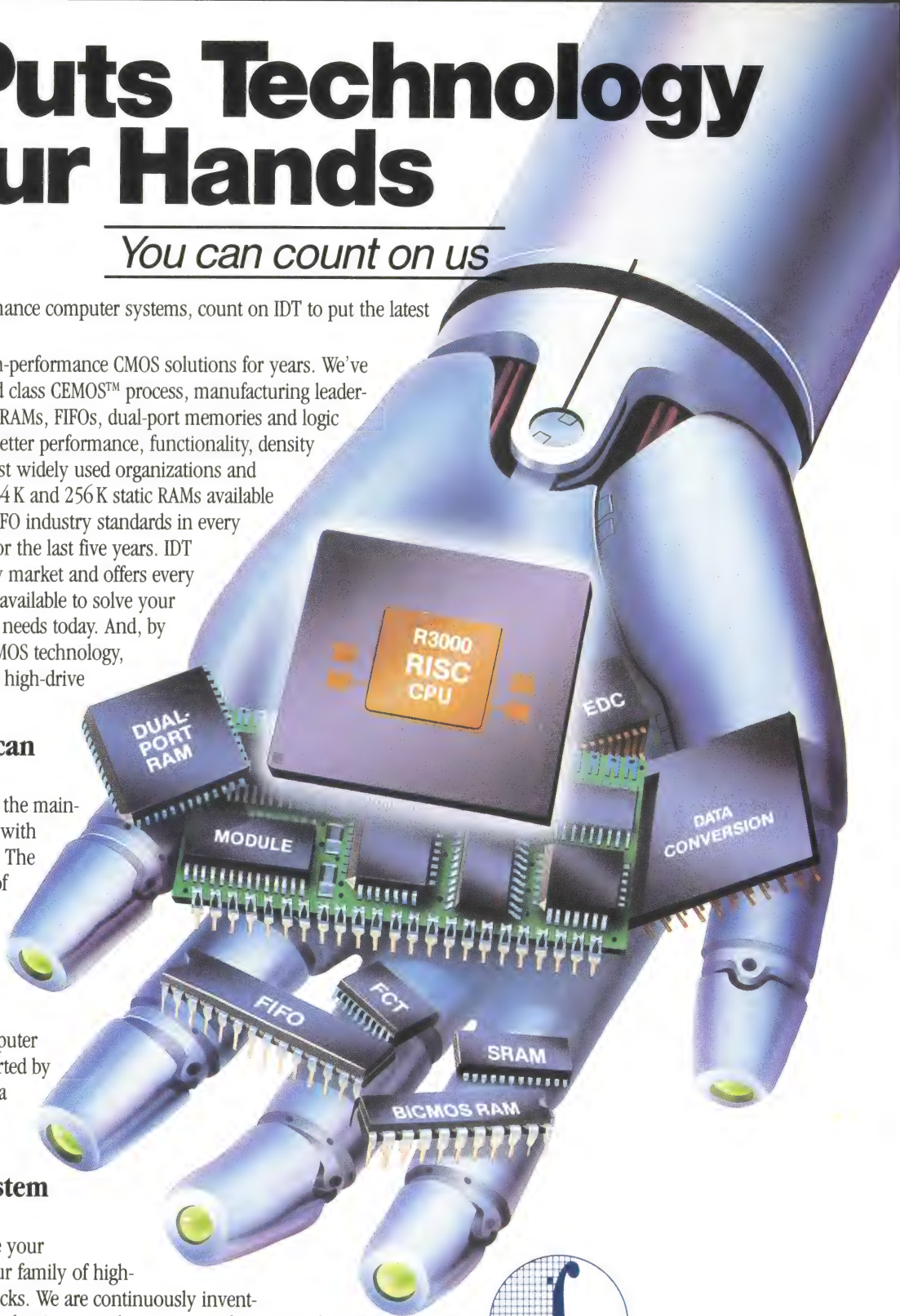
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**CIRCLE NO 111**



## CASE demands much but gives high returns



Users find that CASE tools may not shorten your development time—but for large projects, they reduce both the number of errors and the burden of documentation.

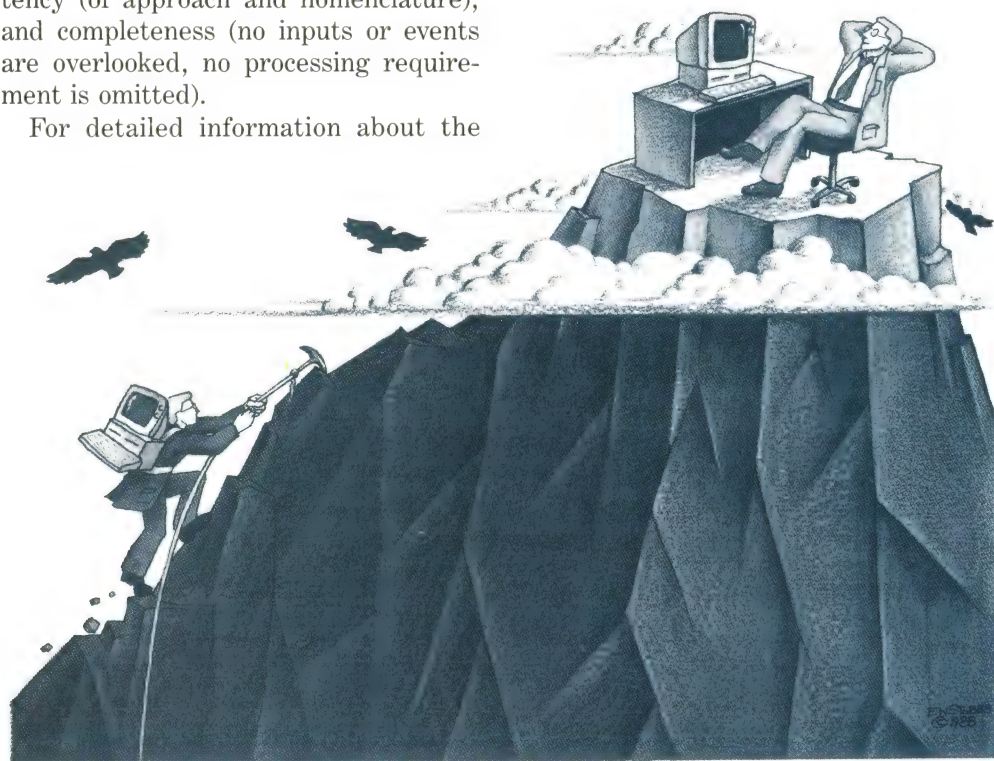
*Chris Terry,*  
*Associate Editor*

**I**n any discussion of CASE (computer-aided software engineering) methods and tools, you're likely to hear somebody say: "... of course, CASE is still in its infancy..." That statement is a half-truth, and you shouldn't let it stop you from seriously exploring and using CASE tools and methodologies. It's true that the tools are young—although the methodologies go back 20 years, actual CASE tools have been available for only about seven years. However, the methods underlying those tools work because they improve the three Cs of good design: communication (between designers and customers, and between the members of the programming team), consistency (of approach and nomenclature), and completeness (no inputs or events are overlooked, no processing requirement is omitted).

For detailed information about the

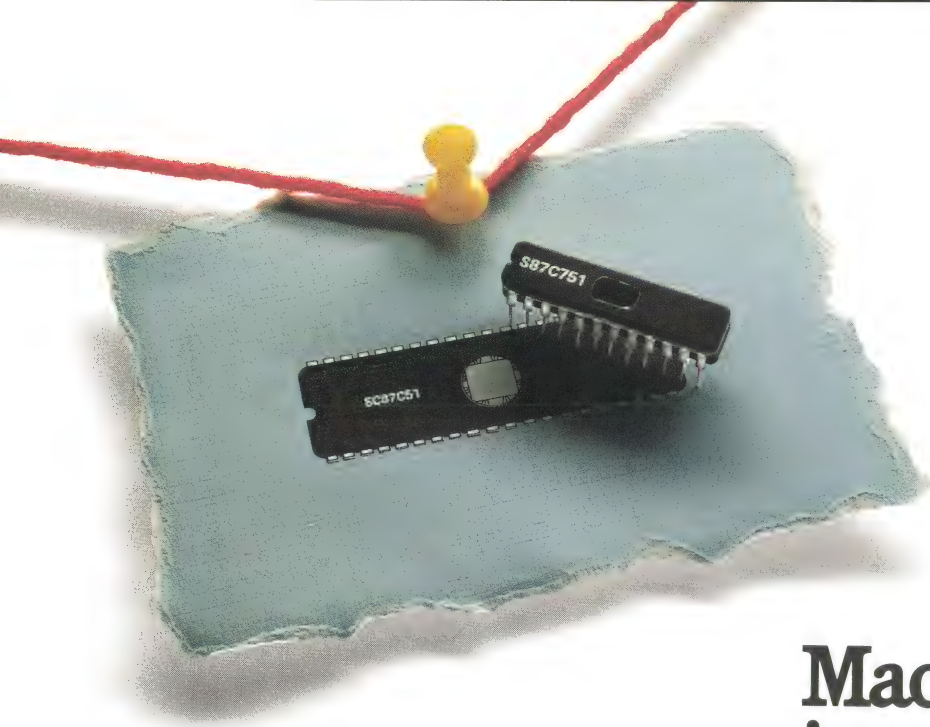
needs of CASE-tool users and how well the tools serve those needs, you can consult the study published by Strategic Focus (**Ref 1**). (A brief summary of the study appeared in EDN, August 4, 1988, pg 267). In a more informal attempt to balance users' experiences against vendors' claims, I spoke with several senior software engineers and managers responsible for large projects. They described large projects as projects that require 10 man/months or have at least 500,000 lines of executable code.

All the engineers and managers I spoke to agreed that a CASE tool is *not* an instant panacea that will solve all



Elizabeth Stubbs





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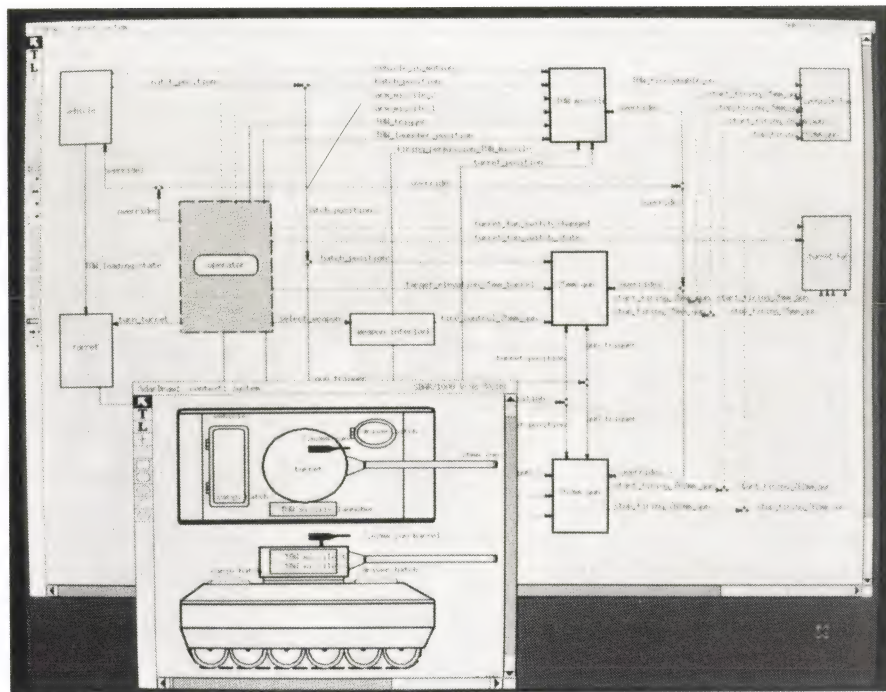
CIRCLE NO 76

EDN January 19, 1989



# TECHNOLOGY UPDATE

## CASE and its users



*You can break a problem down into successively simpler components with Athena Systems's Foresight. You see the "big picture" in the foreground as a frame of reference for the graphical depiction of data flows and processes in the background.*

your design problems, shorten your development time, and write your documentation for you at the touch of a key. Rather, it's a tool that automates much of the grunt work of achieving completeness and consistency in your design and documentation. The price is the time and effort you expend in picking the best tool for your application and then learning how to use the tool effectively.

A CASE tool demands much from you, and some analysts and programmers complain that the discipline imposed by the tool (a "strait-jacket," some claim) restricts or kills their creativity. Peter Craig, who has spent 25 years in software development and is now the president of Promod, a CASE-tool vendor, disagrees. "CASE and software-engineering methods work," he says flatly. In all stages of his career, from individual programmer to manager of team leaders, he has found that CASE methods, whether manual or automated, make it much easier to deliver code that meets user/client expectations

without expensive reworking. He firmly believes that software-engineering methods embody what were called "good programming practices" in the old days, and that these practices encourage, rather than restrict, creativity.

Mark Filteau, vice president of Information Systems at BDM (an aerospace company) confirms that CASE methods and tools work well for large projects. On the issue of creativity, he says: "Most people simply don't realize the degree of discipline that is needed by large projects. You can achieve significant gains by using CASE tools that promote and enforce the discipline within the framework of a methodology that suits your application. Of course you'll encounter resistance, because it's bound to change the way people work." The resistance to CASE, he says, follows a classic sequence of attitudes toward death or any major change: grief, denial, attempts to make a deal, and finally acceptance.

Is such acceptance the end of all existence, or a passage to a higher

plane? Mark's view is that it's both—it's the end of overinflated egos, he says, with the probability of their rebirth as more mature personalities who will, within the framework of the project, unleash their creativity and direct it toward creating an end product of far higher quality.

Mark's most recent experience with large CASE projects began when he took over a large project at BDM. The teams already working on the project had access to Index Technology's \$8400 Excelerator and a variety of 286-based PCs, but did not use the program consistently. Mark provided 386-based PCs for all the teams, and began to enforce the use of the CASE tool. It took about six months to train all the teams to use the tool. During that time, the software engineers also explored the best means of using their chosen methodology for specific projects. (Excelerator lets you choose among several different CASE methodologies. Mark's teams chose the Yourdon-DeMarco methodology with real-time exten-



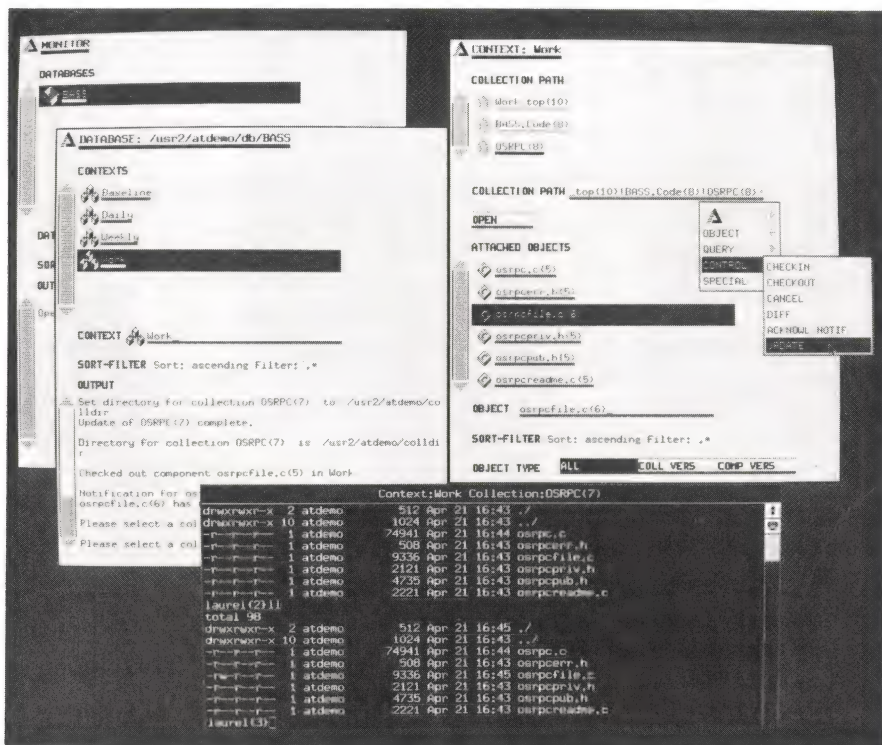
## CASE and its users

Mark also points out that one way of reducing software engineers' resistance to the constraints imposed by the tool is to ask the team's bit-terest CASE critics for advice about how to use the tool, and how to get around its deficiencies so it does what you want it to. Mark found that when they explored the CASE tool's weaknesses, those team members became more familiar with the tool, and they also discovered its strengths. Many of the critics eventually changed their views about the value of the CASE methodology and learned to use the tool competently—some even with enthusiasm.

The small amount of resistance Carol encountered from her software developers did not stem from objections to the tool itself, but rather from the difficulty of using structured-analysis and -design

In Carol's experience, the consistent, guided use of CASE tools in 24 major projects has greatly reduced the problems of maintaining and enhancing the software products. In the analysis and design phases, the CASE tools let you quickly accommodate changes in the requirements, and you can design products for easy expansion and enhancement. In addition, the Customizer tool associated with Excelsior has made it possible to produce quality-control templates for the review of deliverable products, indicating what you have to do to ensure that the design will be complete. Another benefit is just now starting to emerge after two years of archiving all the drawings and data dictionaries. You can reuse complete data-flow diagrams (DFDs), or portions of them, in new projects whose functions are similar to those of the projects for which the DFDs were originally produced.

Bob White and Michael James (not their real names; they both asked that they and their companies



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## CASE and its users

not be identified) are involved in aerospace-related projects and are responsible for the corporate CASE-tool effort. They point out that there's no methodology that's completely suited to all types of applications; each is strong in some areas and weak in others. Also, some of their customers mandate the use of a particular methodology, whereas others prefer to ask the software developers how they'd prefer to approach the problem, and then discuss the suggested approach until they and the developers reach agreement. As a result, Bob and Michael find that their development teams must have access to (and be familiar with) a variety of tools that cover all the major methodologies in current use.

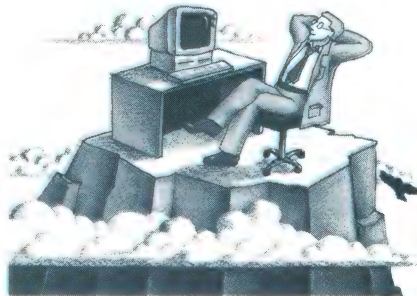
Some (but not all) of the tools allow you to use the methodology of your choice and even to switch notations in mid-project. In such tools, the user interface and commands remain constant. That's a big advantage, because switching tools could mean switching to a different way of working, which would waste time and energy that you could otherwise spend on solving the problem. One finding of the Strategic Focus study was that support for multiple methodologies ranked fifth in importance in 1987, but is projected to rank fifteenth in 1991. Such a projection indicates that this feature will be standard by 1991, so it's not likely to be a big factor in any purchasing decision.

Bob points out that there are very few CASE tools that take you all the way from the most abstract design concepts to usable code. Most of the tools require a manual transform partway through the development cycle, and this discontinuity requires you to shift mental gears. What the tools help you to do, he says, is to take various views of the software objects you're trying to create, and to specify more

and more information about those objects as you get different information from the different views. "As you make the switch from structured analysis, say, to the structured-design modules, that's a major manual transform that is very labor-intensive," Bob says. "You certainly get a different view of the problem, but is the cost of the solution worth the value of the results? That's something you can only decide from your experience."

### Government vs commercial work

Bob, who has worked in the commercial sector as well as the aerospace industry, points out that there's a big difference in what the word "requirements" means to the



two sectors. "When a software house is trying to come up with a new product, it all too often means that engineering and marketing get together in a big room, and whoever shouts loudest determines the requirements. Then engineering goes away and prepares a spec, which probably only one or two people look at. The final code will probably be close to the spec, but if it matches the real requirements, that's quite a surprise. In the aerospace industry, however, there are two fundamental requirements: You must deliver a product that meets all of the customer's requirements, and you must not deliver any module that does not meet any of the customer's requirements. This is the real value of the front-

end CASE tools; you may have thousands of initial and derived requirements, all of which have to be tracked through various versions of the system, and this is what the tools are good at."

Both Bob and Michael emphasize that all of the CASE tools available have three major components: a user interface, which may be no more than a command-line facility; a data repository which may be one-way (such as a compiler) or two-way; and some transform process. Currently, however, each CASE tool's user interface is not only different from all the others, but incompatible with them, especially when it comes to graphics interfaces. Bob and Michael believe, however, that the resulting chaos will disappear when graphics interfaces (such as X-Windows) evolve to the point where there is a universally acceptable standard.

### The evolution has already started

Some large companies are now starting to install unifying tools that operate at the network level, such as the Sun Microsystems NSE (Network Software Environment) and Atherton Technology's Software Backplane. These tools are aimed at providing a consistent user interface (X-Windows) and object-oriented data storage for all the data related to a given project, including data generated by a wide variety of software-development tools.

Jon Squire, section manager of software development at Westinghouse, says that his company finds the Software Backplane's object-storage manager invaluable in accommodating data generated by a very wide variety of CASE tools and other development tools, many of which are not directly compatible with each other. Jon is engaged in a constant search for development tools that can handle very large pro-



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# TECHNOLOGY UPDATE

## CASE and its users

jects. "We buy a lot of tools," he says, "and develop some of our own. We're finding that there are plenty of point solutions—tools which are suitable for a particular type or size of application, but generate data that we can't directly use in other tools, or which run out of power when the project gets very large. We need the flexibility to try out many tools and to make them work together." Jon also points out that many CASE tools make it difficult for you to change naming conventions when a project is already underway and the diagrams and specifications are already in the database. The object-oriented data repository helps to solve this kind of problem.

### CASE helps with documentation

CASE tools can also help you prepare complex documentation for your projects. When you design software systems for government agencies, for example, the burden of documentation becomes not just significant, but almost overwhelming. DoD-STD-2167 demands many different documents and a great deal of cross-referencing between

them. Most CASE tools can provide many kinds of reports, but they can't satisfy all of the DoD-STD-2167 requirements. Thus, there's a great deal of pressure from users for the creation of easy links between CASE tools and documentation tools. Context (from Context Corp), for example, a highly sophisticated documentation tool, provides a link that can request Cadre's TeamWork or Teledyne Brown's Tags to provide text, specifications, or graphics in print-image form. Context can then convert the print to its own internal-storage form for processing. Context runs on Apollo Domain workstations. Prices start at \$16,900 for a basic documentation-management workstation; the many optional packages can add considerably to this price.

If you use Excelerator, you have other possibilities. Mark Filteau's group has used the \$12,500 Customizer option to create a link between Excelerator and the Ventura desktop-publishing package that the group already owned. The link has proved highly successful. Says Mark: "CASE vendors don't like to

hear this, but by far the biggest productivity gain (as much as 30%) comes from an interface to a good documentation system—and it's immediate. From the CASE tools alone, you see quality improvement quickly, but productivity gains only appear when everyone is familiar with the tools, and they're not on the same scale as the gains from the documentation tools."

Bob White points out that you can also obtain the CASE/documentation link via the Software Backplane, especially with such tools as IDE's Software Through Pictures, which has a completely open architecture. "The bad news," he says, "is that to adapt your tools to a standard data repository like that of the Software Backplane is a lot of work, and a lot of risk. The CASE vendors aren't going to put that work in until some sort of standard begins to evolve. Once there's some sort of standard, a vendor can say, 'If I interface to this standard there's a probability that other folks will too, and that'll give me some leverage, and make the risk worthwhile.' Then there'll be some movement forward—but I don't see that

## For more information . . .

For more information on the CASE tools discussed in this article, contact the following manufacturers directly, circle the appropriate numbers on the Information Retrieval Service card, or use EDN's Express Request service.

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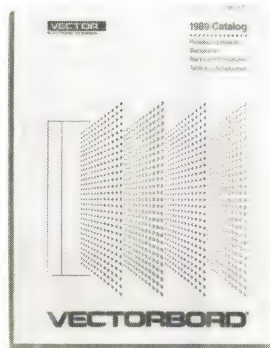
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## TECHNOLOGY UPDATE

### CASE and its users

kind of standard happening until the hardware vendors step up to it."

The established CASE tools have made a lot of evolutionary progress, but show no startling developments. The established tools fall into a few general classes: front-end tools for requirements analysis and more detailed software-module design (including real-time interactions); back-end tools such as compilers, syntax checkers, configuration- and version-control tools, and reverse-engineering tools; and a rather hazy middle ground of frame generators and full-code generators. Previous EDN articles have described these classes in considerable detail (Refs 2, 3, and 4).

An interesting new development, however, is the appearance of two simulators to enhance the CASE armamentarium. Both products—i-Logix's Statemate and Athena Systems' Foresight—allow you to define a model of the system you're designing in terms that are precise enough for the computer to understand and execute. You can run the simulation interactively and watch the highlighted flow of data and control events on the screen; or you can run the simulation as a batch job that will generate whatever reports you need.

Statemate runs on Sun, Apollo, and MicroVAX machines. A basic module costs \$10,000, and a fully configured seat with all four modules costs \$75,000, regardless of the host architecture. Statemate gives you three different views—behavioral, functional, and structural—of a reactive, real-time system. It includes validation procedures, and it lets you control the simulation interactively. Statemate is intended primarily for the design of embedded systems. However, Westinghouse's Jon Squire says that the people in his company who develop transaction-driven business applica-

tions find it very valuable for medium-size projects (they say it tends to bog down, though, when the project size exceeds 150,000 lines).

Foresight, which Athena Systems announced in October 1988, currently runs on Sun workstations under Unix and costs \$23,000 per user for a license that allows as many as 10 users. The program was created specifically to aid in the design of real-time embedded systems, and is based on the Executable Structured Modeling (ESM) techniques that Athena developed as an extension of the well-known real-time structured-analysis methods. Foresight comes with a graphics editor for creating specification diagrams and building a model; an executable library of basic real-time functions; tools that let you create custom library elements; an analyzer that checks your model for completeness and consistency; and an interactive, discrete-event simulator that checks the functional and timing behavior of your model under various conditions. **EDN**

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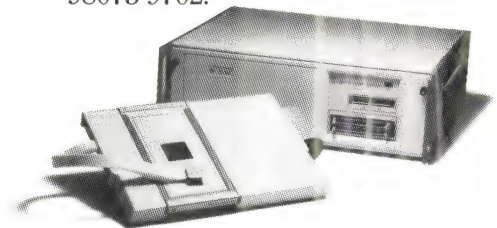
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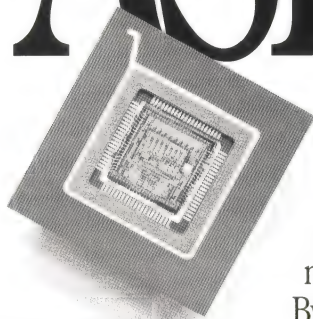
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## CHOPPER-STABILIZED OP AMPS

# Improvements make precision amps easier



Manufacturers are making quieter chopper-stabilized op amps that are also easier to use.

**Richard A. Quinell,**  
Regional Editor

**C**hopper-stabilized op amps offer extremely low input offset voltages ( $V_{OS}$ ) and have virtually no offset-voltage drift over time or temperature.

Until recently, however, these op amps exhibited excessive clock noise and long overload recovery times; in addition, they all required external holding capacitors. Over the past 18 months, various op amps have appeared that solve those problems, making it easier to build high-precision circuits that use chopper-stabilized devices.

Low offset-voltage drift is probably the most attractive characteristic of chopper-stabilized op amps. Applications that take advantage of this feature include strain-gauge amplifiers, thermocouple amplifiers, and precision data col-

lection in environments where periodic adjustments are either impractical or impossible. Most often these applications involve low frequency signals (less than 10 Hz).

### Self-correcting offset

**Fig 1** shows the basic operation of a chopper-stabilized op amp. The device consists of a clock generator, a main and a nulling amplifier, and two holding capacitors, which can be either internal or external. The main amplifier has fixed connections to the input and output pins.

The nulling amplifier alternately performs two tasks: First, it uses a holding capacitor ( $C_1$ ) to store a correction for its own offset, which is measured while the amp's input pins are shorted. The

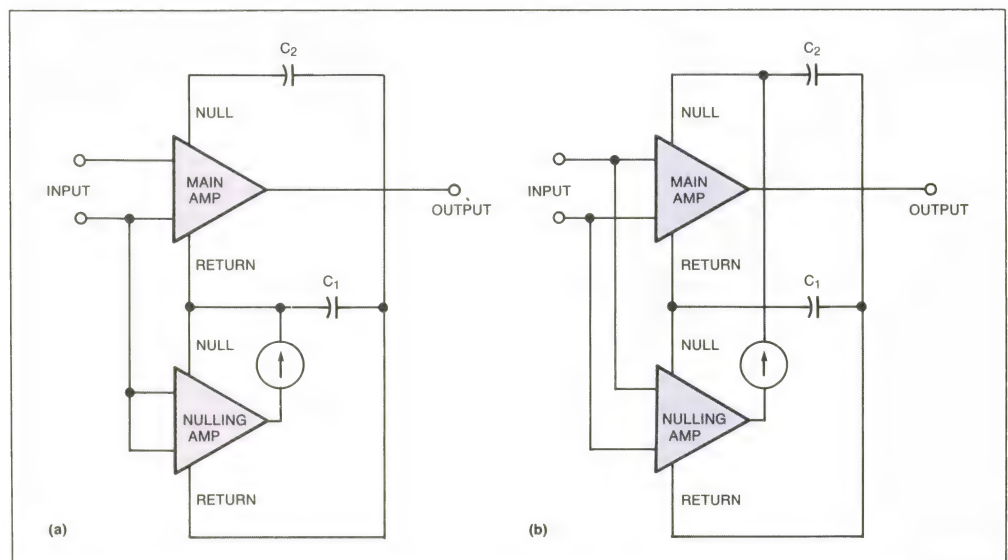


**Fig 1—The nulling amplifier first corrects itself (a) by using its output signal with its input lines shorted. The signal is stored in holding capacitor  $C_1$ , which is connected to the null input of the nulling amplifier. The nulling amp then corrects the main amp (b) by measuring the input signal. The correction is stored in holding capacitor  $C_2$ , which is connected to the null input of the main amplifier.**



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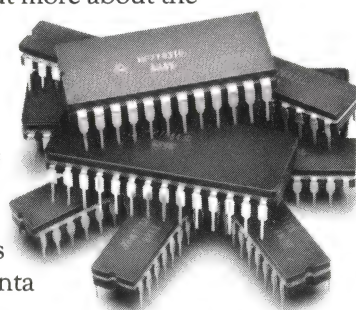
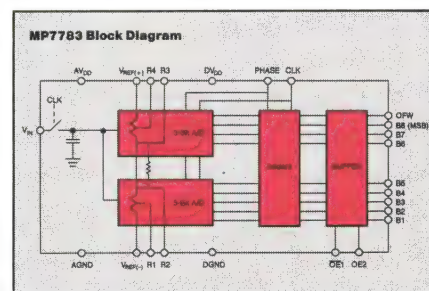
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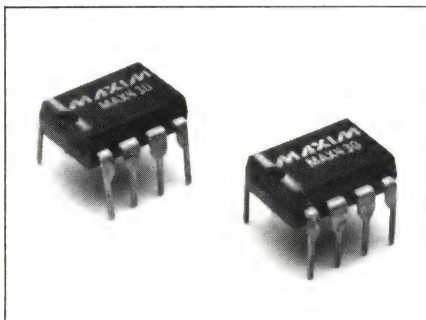


# TECHNOLOGY UPDATE

## Chopper-stabilized op amps

nulling amp then measures the offset of the main amplifier and stores a correction voltage in another capacitor ( $C_2$ ). The amplifier alternates between these tasks at the rate of the clock.

Because the op amp is constantly correcting its offset, offset voltages are low, and drift is virtually nonexistent. The Intersil ICL7650S has specifications typical of those achieved using chopper stabilization. This device has a maximum  $V_{OS}$  of 5  $\mu\text{V}$  and an input bias current of 10 pA at 25°C. Its offset drift averages 0.02  $\mu\text{V}/^\circ\text{C}$  within the range of  $-25^\circ\text{C}$  to  $85^\circ\text{C}$  and its long-term drift stability is 100 nV/ $\sqrt{\text{month}}$ . Its noise specification is 2  $\mu\text{V}$  p-p (dc to 10 Hz). Manufactur-



*The MAX430 has chip capacitors bonded to the lead frame. It operates at  $[\pm 15\text{V}]$  and can directly replace the LM108,  $\mu\text{A}741$ , or OP-07 in many applications without re-wiring.*

ers do point out that the data-sheet numbers for chopper-stabilized op amps actually represent the limits of test capabilities, not the real—and in fact better—performance of

the devices themselves (see **box**, “Good thermal design minimizes drift”). You can order the ICL7650S in either an 8-pin or a 14-pin version for \$1.99 and \$2.70 (100), respectively.

### Built-in hold capacitors

The ICL7650S requires external holding capacitors to operate, but a number of chopper-stabilized op amps have those capacitors built in. The Maxim MAX430 has 0.1- $\mu\text{F}$  chip capacitors bonded to the lead frame within the device; it operates at  $\pm 15\text{V}$ . These two features allow you to directly replace conventional LM108s or  $\mu\text{A}741$ s with MAX430s in many applications. In addition the MAX430 corrects its own offset

## Good thermal design minimizes drift

Specifications are only as good as the precision of the tests that define them. The manufacturers’ testing capabilities usually yield an offset-voltage drift specification of 0.05  $\mu\text{V}/^\circ\text{C}$ ; actual performance is probably better. To get the best actual performance from these op amps, however, you should also pay close attention to the thermocouple effect.

Any connection of dissimilar metals forms a thermocouple, producing an electric force that varies with temperature. Connectors, switches, resistors, and even copper wire can produce thermal EMF. A junction between copper wire from two different manufacturers, for example, can generate as much as 0.2  $\mu\text{V}/^\circ\text{C}$ . The junction between a circuit-board trace and the Kovar wire used as package leads generates nearly 35  $\mu\text{V}/^\circ\text{C}$ —700 times that of a typical drift specification.

Because of thermal EMF, it’s good practice to minimize the number of junctions in the amplifier’s input signal path. You could, for example, attach the sensors directly to the circuit board rather than go through a connector. When connectors, sockets, or switches are necessary, you should select them for their low thermal EMF.

Balancing the type and number of junctions in the input path helps reduce thermal errors by providing differential cancellation. This technique may require you to introduce normally unnecessary junctions to

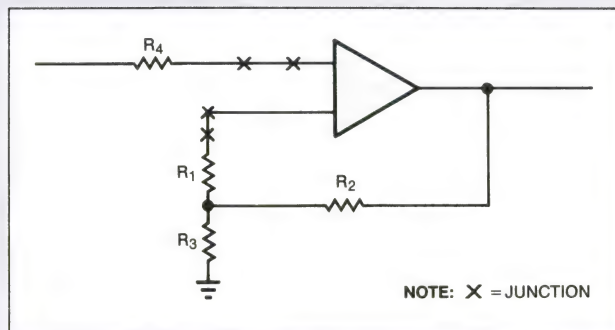


**Fig A—Resistor  $R_1$  brings the input circuits into thermal balance. Both input pins see the same type and number of potential thermocouple junctions.**

offset unavoidable ones. An example of this is shown in **Fig A**, where resistor  $R_4$  has been added to thermally balance  $R_1$ .

If temperature changes across the input circuit the amplifier sees thermal errors, even with balanced junctions. A  $1^\circ\text{C}$  shift across a metal-film resistor produces 20  $\mu\text{V}$  of thermal EMF.

For good thermal design, you should also keep heat sources such as power transistors several inches away from an amplifier circuit and avoid air flow over the amplifier area. You may also need to enclose the amplifier and associated components in some form of thermal baffle to reduce the effect of air currents.



# TECHNOLOGY UPDATE

## Chopper-stabilized op amps

voltage, so you don't have to make manual adjustments or use trimming resistors. The MAX430 costs \$5.65 (100).

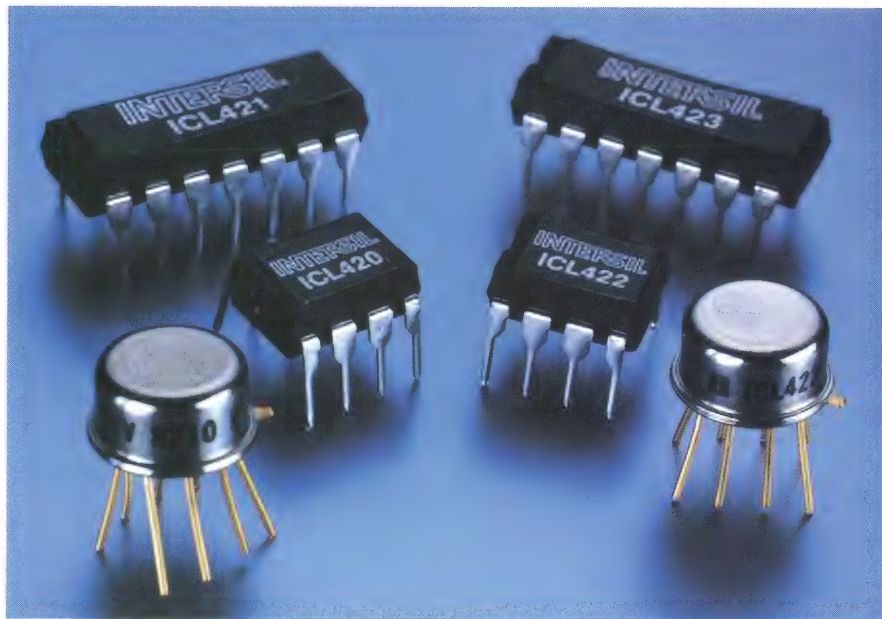
The Teledyne TSC901 Series also features built-in capacitors, which are integrated with the circuit in silicon. Because the capacitors are small—typically 100 pF—the noise specifications of the TSC901 are somewhat greater than average. The device has a  $V_{OS}$  of 15  $\mu$ V and an input noise voltage of 5  $\mu$ V p-p (dc to 10 Hz). (The MAX430, in comparison, has an input noise voltage of 1.1  $\mu$ V p-p, dc to 10 Hz.) The TSC901 Series are available in single-, double-, and quad-amplifier packages, which cost \$2.36, \$3.94, and \$10.80 (100), respectively.

The LTC1050 from Linear Technology Corp also has on-chip capacitors, but has managed to solve the noise problems usually associated with small holding capacitors. The manufacturer specifies input noise at 1.6  $\mu$ V p-p (dc to 10 Hz); the long-term offset-voltage drift is 50 nV/ $\sqrt{\text{month}}$ . The LTC1050 costs \$2.25 (100).

For amplifiers that don't have built-in capacitors, such as the Intersil 7650S and the 420 Series from Intersil and Maxim, you must select the hold capacitors carefully. Noise really isn't the critical issue; any low-leakage capacitor is adequate in this regard. But settling time is an issue; capacitors with a high dielectric absorption, such as ceramic capacitors, can take several seconds to settle after power is first applied. Therefore you should use Mylar or polypropylene capacitors if you need fast initial settling.

### Overload recovery is long

Long overload recovery times have plagued chopper-stabilized op amps in the past. If the main amplifier is driven to saturation, the nulling amplifier sees an imbalance at the main amplifier's input termi-



*These chopper-stabilized amplifiers from Intersil feature a typical offset voltage of 1  $\mu$ V, offset drift of 0.02  $\mu$ V/ $^{\circ}$ C, and  $[+/-]15$ V operation. The 14-pin versions also offer clamp circuitry and external clock controls.*

nals and tries to correct that imbalance in the same way that it corrects an offset error. As a result, both amplifiers drive to the rail, and the holding capacitors acquire excessive charges. Because the nulling amp can only make small corrections, it takes a long time to reduce those charges once the overload is removed.

Although an overload recovery time can last several seconds, the

typical time required for a chopper-stabilized op amp is something longer than 100 msec, which is unacceptable in many applications. The LTC1050 has faster recovery times: 1.5 and 3 msec for positive and negative saturation, respectively. But even those recovery times are slow in comparison to conventional op amps, which usually recover from overloads in less than 10  $\mu$ sec.

To avoid the recovery-time problem, many chopper-stabilized op amps offer clamp circuits that you can use to prevent the amplifier from reaching the saturation point during an overload. Maxim's MAX421/423, Intersil's ICL7650S, and Linear Technology's LTC1052 all have circuits similar to Fig 2. When  $V_{OUT}$  approaches either rail, the appropriate clamp transistor begins conducting. If you connect the clamp pin to the amplifier's inverting input pin, you put that transistor in parallel with the gain resistor. As the transistor conducts, it reduces the gain of the amplifier, thus preventing saturation.

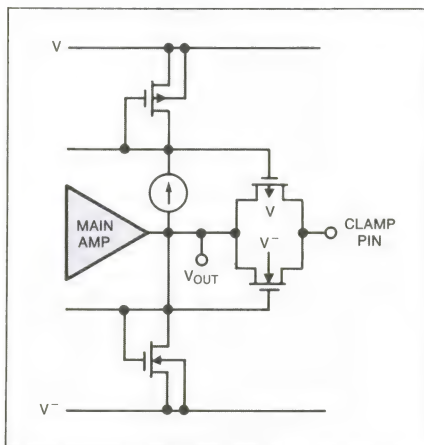


*Fig 2—Many chopper-stabilized op amps use this clamping circuit. It prevents the op amp from reaching the saturation point during an overload.*



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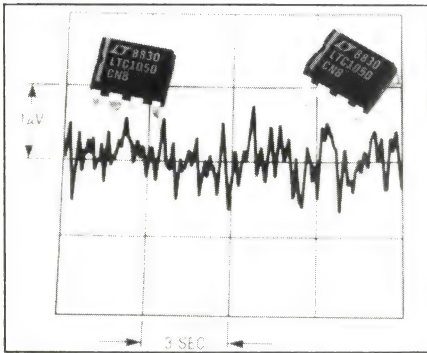
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# TECHNOLOGY UPDATE

## Chopper-stabilized op amps

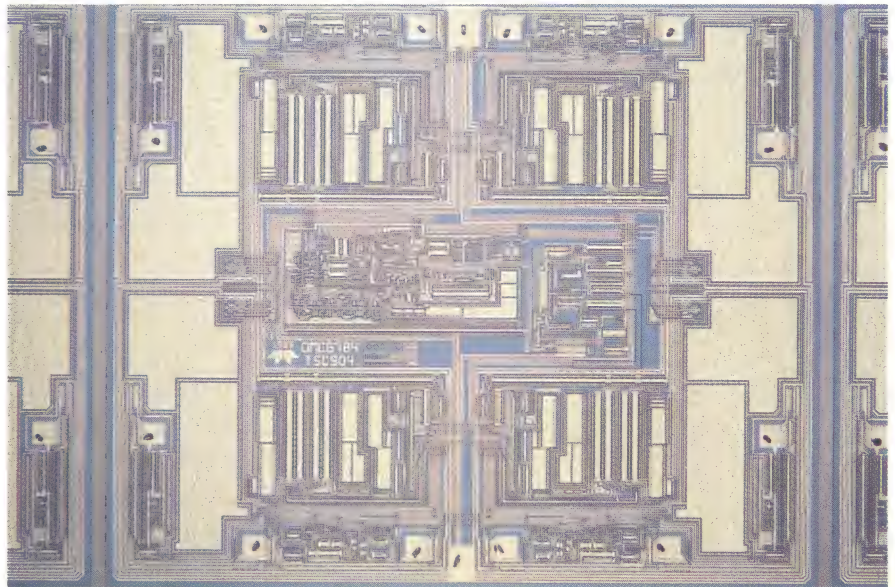


*The LTC1050 chopper-stabilized op amp offers built-in capacitors and an input noise specification of 1.6  $\mu$ V p-p. The part also allows you to use an external clock to set the chopping frequency.*

But using the clamp has two drawbacks. First, the available output range of the amplifier is reduced by as much as 1V from each rail. Second, the leakage of the clamp transistors shows up as additional bias current at the input and thus reduces accuracy. Typical leakage currents range from 1 to 10 pA.

The sampling techniques that chopper-stabilized op amps use to eliminate drift can result in intermodulation as well as clock noise. Interaction between the input signals and the clock can generate intermodulation products in the form of sum and difference signals. If the input signal's frequency is close to the rate of the clock, the difference product shows up as additional offset error. You can eliminate this error by filtering the input signal to keep its frequency range well below the sampling clock frequency; the clock frequency is typically in the range of 300 to 600 Hz (although the LTC1050's frequency is 2.5 kHz typ). Filtering also allows you to reduce clock noise; you can do this by restricting the amplifier's bandwidth or by filtering the output.

If, on the other hand, your application requires a wide bandwidth for the system as a whole, you still have some options. The MAX421/423, the LTC1050/1052, the ICL7650, and the TSC901 all



*The built-in hold capacitors on Teledyne's 904 quad chopper-stabilized op amp appear as large metal areas at the chip's edges.*

allow you use an external signal to set the amplifier's clock frequency. Thus you can, for example, synchronize the amplifier with the sampling clock of an A/D converter, thereby ensuring that the clock noise is never sampled. You can also synchronize two amplifiers to reduce overall noise in differential applications.

Having control of the sampling clock frequency gives you two additional benefits: You can use the external clock to prevent the nulling

amplifier from responding to an overload. By holding the clock low, you keep the nulling amplifier in its self-nulling state. You can also avoid intermodulation problems by setting the clock frequency away from strong signal frequencies.

**EDN**

Article Interest Quotient  
(Circle One)

High 518 Medium 519 Low 520

## For more information . . .

For more information on the op-amp products discussed in this article, contact the following manufacturers directly, circle the appropriate numbers on the Information Retrieval Service card, or use EDN's Express Request service.

**GE Solid State/Intersil**  
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Cupertino, CA 95014  
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Mountain View, CA 94039  
(415) 968-9241  
TWX 910-379-1590  
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(408) 432-1900  
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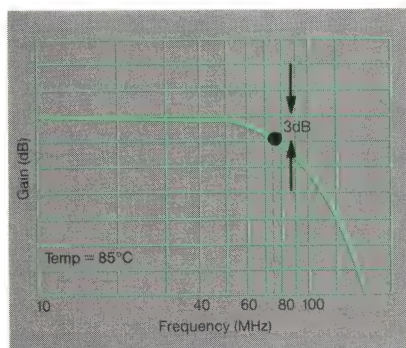
# Now there's a high performance single-chip solution for quantizing fiber optic signals.

Micro Linear's new ML4421 is the first complete solution for converting low-level analog pulses from a fiber optic PIN diode preamp to digital signals, enabling you to interface with the clock recovery circuit.

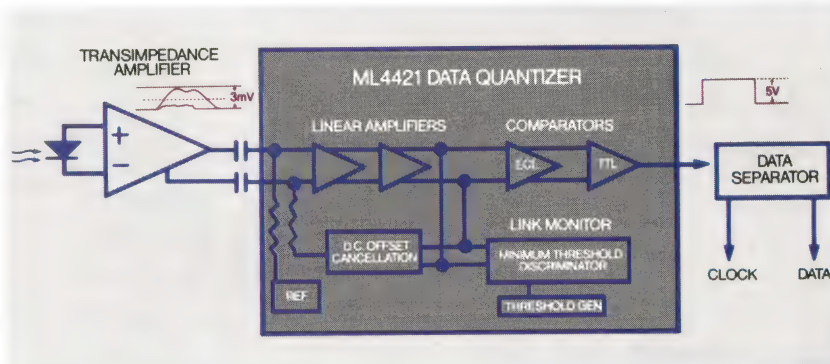
## High Frequency Design Made Easy

The ML4421 contains all the necessary circuitry for quantizing signals at data rates up to 100Mbaud. The chip includes a high speed comparator, wide band amplifier, a link monitor and a DC offset cancelling circuit. The high level of integration greatly simplifies the design of a fiber optic receiver by eliminating multiple discrete devices.

The new ML4421 data quantizer can accept a wide dynamic range of signal strengths at its input, up to 55 dB.



*ML4421's Wide Bandwidth makes it usable to 100 Mbaud*



*ML4421 converts Low Level Pulses from PIN Diode Preamp into Clean Digital Signals*

This wide dynamic range means the ML4421 can be used where combinations of high and low voltage input levels might saturate less accommodating, discrete solutions. The quantizer's low noise voltage (25 $\mu$ V) makes its contribution to system noise insignificant compared to other components.

Once your data signal has gone through two cascaded stages of wideband (50MHz) gain amplification, you can choose between either a single +5V TTL comparator, or a +5V or -5.2V ECL comparator to interface with other blocks.

## Built-In Link Monitor

A user adjustable link monitor prevents incorrect data from being passed by disabling data outputs when incoming signals fall below externally set threshold

levels. The circuit also transmits a status signal to the system.

## Easily Customized

The ML4421 is developed on Micro Linear's FB300 family bipolar tile array platform. It allows easy customization to your specific applications, including smaller packages or changes in I/O and functions.

## Call Or Write For More Information

If you would like more information on the ML4421 fiber optic data quantizer, or on Micro Linear's complete line of linear devices, call (408) 433-5200, extension 900. Or write:

Micro Linear  
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CIRCLE NO 89



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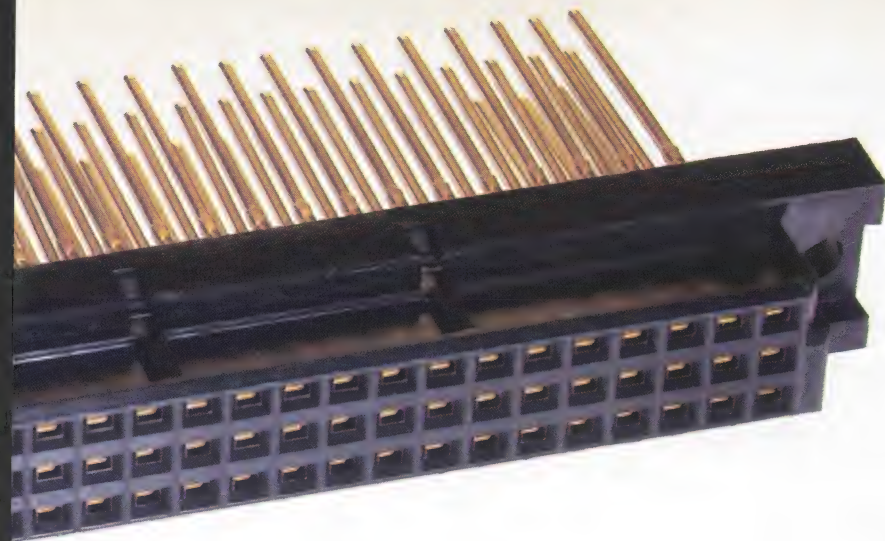
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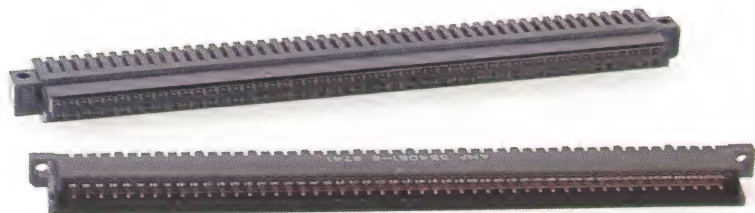
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CIRCLE NO 74



## Pocket-size in-circuit emulator for 8051 starts at \$995

The ubiquitous 8051 8-bit micro-controller is popular for many controller applications. Until now, you had to spend a few thousand dollars in order to get an in-circuit emulator that would help you in your software development efforts. The cost of the d<sup>2</sup>ICE-51 in-circuit emulator for the 8051 starts at a figure less than one thousand dollars.

The d<sup>2</sup>ICE-51 consists of two components, the hardware module and the controlling software that runs on an IBM PC, PC/XT, PC/AT, PS/2, or a compatible computer. The software that controls the d<sup>2</sup>ICE-51 is similar to the company's software simulator. This simulator is a multiwindowed environment that allows you to control the operation of the 8051. You can run your code and watch the source code, registers, memory accesses, I/O operations, traces, and other valuable displays on the screen at the same time. You can set up a flow window to show a disassembled trace, a histogram to view high-speed operation and number of

interrupts, or a flow chart.

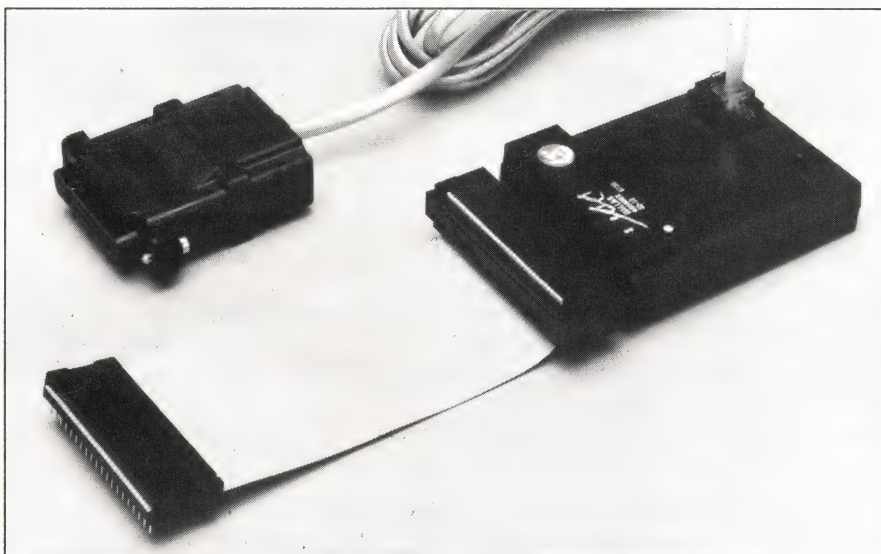
The hardware portion of the d<sup>2</sup>ICE-51 is based on the DS5000 from Dallas Semiconductor and includes as many as 32k bytes of on-chip RAM. The emulation socket is plugged into the target system, and an RS-232C cable plugs into either COM1 or COM2 of an IBM PC. Because the target system provides the power for the emulator, applications that have tightly budgeted power may not be able to power the standard unit; for these low-power applications, a CMOS version of the d<sup>2</sup>ICE-51 is available.

The standard d<sup>2</sup>ICE-51 with 4k bytes of memory costs \$995; the 28k-byte standard version sells for \$1250. The price of a low-power CMOS version with a 4k-byte memory is \$1195, and the 28k-byte CMOS version costs \$1495.

—David Shear

*Cybernetic Micro Systems Inc,  
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Circle No 446



*The pocket-size in-circuit emulator for the 8051 allows you to easily debug your software and test the system in real time.*

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### MODEL 824 PORTABLE PROGRAMMER

#### ● PROGRAMS:

- **16K to 1024K Bit E<sup>2</sup>/EPROMs** from all manufacturers (more than 220 devices)
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#### ● FEATURES:

- **64K Byte standard RAM** (expandable to **256K Byte**)
- **Built-in UV eraser**
- **Fully programmable VCC & VPP** for future programming needs
- **Plug-in SOFTPACK cassette** for do-it-yourself software updates
- **Detects Device type** (signature)
- **Detects misplaced device**

#### ● SUPPORTS:

- 5 different programming algorithms, including **Intel Intelligent** and **Quick-Pulse, AMD Flashrite**

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- **16K to 1024K Bit E<sup>2</sup>/EPROMs** from all manufacturers (more than 220 devices)
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- **8, 16, 32 bit or GANG operations**
- **64K Byte standard RAM** (expandable to **256K Byte**)
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- Fully **programmable VCC & VPP** for future programming needs
- **Detects Device type** (signature)
- **Detects misplaced device**

● **SUPPORTS:**

- 5 different programming algorithms, including **Intel Intelligent** and **Quick-Pulse, AMD Flashrite**

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## PRODUCT UPDATE

### In-circuit ASIC verification tool checks designs before prototypes

The Rapid Prototype Machine (RPM) Emulation System is a real-time, in-circuit, ASIC verification tool based on Xilinx's Logic Cell Array (LCA). You can design a circuit for ASIC implementation, transfer the design to the RPM hardware, plug the RPM emulator into your target system, and prove that the logic works in concert with the target system. If it doesn't work, the emulation system lets you reconfigure the LCAs to debug and correct problems.

The basic RPM configuration supports real-time emulation of designs with as many as 25,000 gates. Modular expansion permits the gate capacity to grow to 100,000 gates. Stimulus generation and logic

analysis are built into the basic configuration. Interface cables and plug adapters insert into standard ASIC sockets, and optional component adapters allow the use of standard components, such as memory devices and  $\mu$ Ps as part of the emulation.

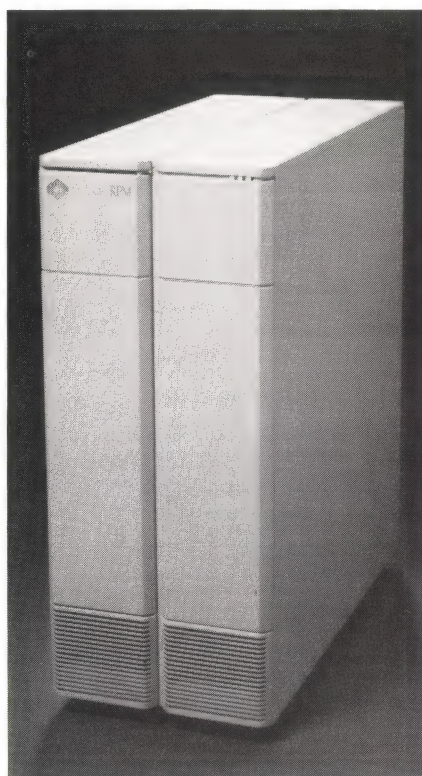
The RPM Emulation System consists of stand-alone emulation hardware and software. The software is made up of the emulation setup and embedded design-analysis tools. An Ethernet interface or a SCSI port connects to your workstation—either Daisy or Valid, and by the end of the first quarter 1989, Mentor—and allows the workstation to control the emulation system.

The system is currently in beta test, and the vendor is scheduling production shipments for the end of the first quarter 1989. Pricing for the Rapid Prototype Machine Emulation System begins at \$125,000.

—**Michael C Markowitz**

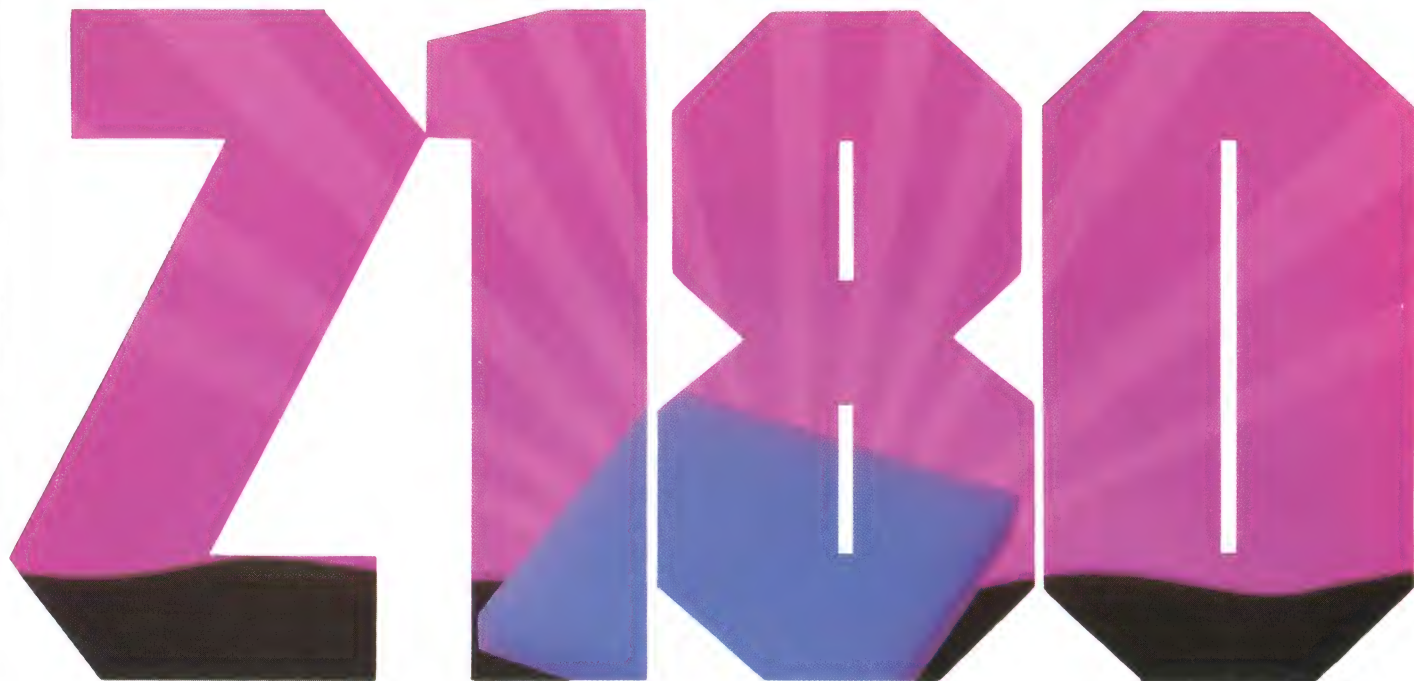
*Quickturn Systems Inc, 1023 N Shoreline Blvd, Mountain View, CA 94043. Phone (415) 967-3300. FAX 415-967-3199.*

**Circle No 730**



*Using the RPM Emulation System, you can verify and debug the design of your ASIC in its target system in real time.*





# Great code compatibility. Terrific performance. Superintegration.™

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## Full software compatibility.

You'll be up and running with the Z180 immediately. Because it's 100% object code compatible with Z80/8080.™ You probably already know the code, so you can port right onto the Z180. Not only that, since Zilog originally developed the part jointly with Hitachi, the Z180 is directly compatible with Hitachi's version, the HD64180Z.™

## Enhanced performance.

Of course, the Z180's CPU core gives you more power and speed than discrete CPUs. Besides that, there are several new instructions. You also get operating frequencies to 10 MHz. And you have the overall performance advantages of CMOS and Superintegration.™

## The important peripherals are on board.

The Z180's high integration results in impressive savings in costs and real estate. The MMU gives you one Mbyte of addressing space. You have 2 DMA channels, 2 UART channels, and 2 16-bit programmable counter-timers. Plus wait-state generators, an interrupt controller, a clock oscillator/generator, and a clocked serial I/O port. All integrated on the Z180 chip.

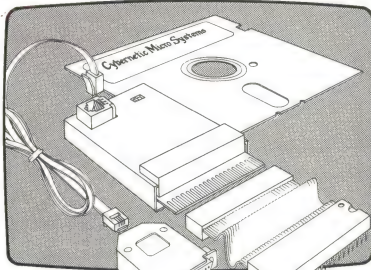
If this isn't enough to convince you to take a look at what the Z180 can do for your design project, here's a little more to consider. The full complement of development support tools are readily available from industry leaders. And the Z180 comes to you off-the-shelf, backed by Zilog's proven quality and reliability. Find out more about the Z180 or any of Zilog's growing family of Superintegration products. Contact your local Zilog sales office or your authorized distributor today. Zilog, Inc., 210 Hacienda Ave., Campbell, CA 95008, (408) 370-8000.

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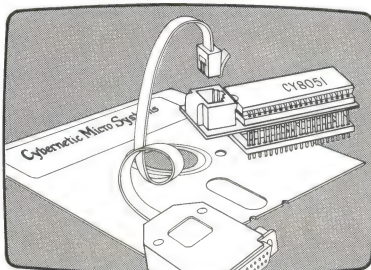


## Low Cost 8051 Tools



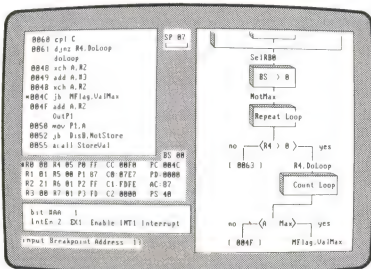
### d<sup>2</sup>ICE-51 \$995

This Real-Time ICE is the lowest cost and smallest sized full speed 8051 in-circuit emulator. Full access to hardware I/O. Includes all debugging features of Sim and dICE below. Fits in shirt pocket.



### dICE-51 \$495

This reduced-speed in-circuit 8051 debugger provides full access to I/O but will not run real-time. With the same user interface features as Sim8051 below, dICE-51 generates execution profiles during reduced speed execution. (CMOS and MIL also available.)



### Sim8051 \$395

This software Simulator/debugger allows 'no-circuit' debugging of 8051 code on IBM-PCs. All Cybernetics 8051 debug tools offer multi-window source code displays, symbolic access to data, single key commands, breakpoints, trace, full speed and single step execution, execution profiler, and more.

### Other 8051 tools include:

Cross Assembler \$195  
8751 Programmer \$195-\$345  
Debugger Demo Disk \$ 39



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CIRCLE NO 10

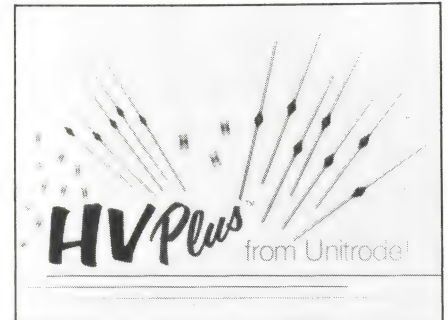
## PRODUCT UPDATE

## High-power rectifiers feature 30-nsec recovery times

The HV Plus Series high-speed rectifiers enhance the design and performance of high-voltage, high-frequency switching power supplies. Featuring reverse voltage ratings of 200 through 1000V and reverse recovery times as fast as 30 nsec, the rectifiers enable you to improve performance in difficult applications. For example, HV Plus rectifiers can serve as clamp diodes to protect high-voltage power MOSFETs or as output rectifiers in high-frequency converters. Available in both industrial and high-reliability/MIL-grade versions, the rectifiers have an 8-pF junction capacitance and low leakage characteristics at high temperature.

The average dc output-current rating measures 2A for the UHVP202-UHVP210 industrial versions and the 1N6620-1N6625 high-reliability rectifiers; the industrial-grade UHVP402-UHVP410 and the high-reliability 1N6626-1N6631 feature a 4A current rating. At 25°C, reverse leakage current ranges from 1 to 2  $\mu$ A for the 2A industrial units and from 0.5 to 1  $\mu$ A for the 2A high-reliability units. Respective ratings for the 4A units are 4 to 5  $\mu$ A and 2 to 4  $\mu$ A. At 125°C, reverse leakage measures 100 to 150  $\mu$ A for the UHVP202-UHVP210 devices and 250 to 500  $\mu$ A for the UHVP402-UHVP410 units. Maximum reverse leakage current at 150°C is 300 and 1000  $\mu$ A for the 1N6620-1N6625 and 1N6626-1N6631 rectifiers, respectively.

Although these specifications are impressive, they reflect performance in an industry-standard test circuit. To help designers address more realistic problems, the com-



Available in 2 and 4A versions, HV Plus rectifiers feature reverse recovery current ratings of 30 nsec and reverse voltage ratings to 1000V.

pany has characterized all HV Plus rectifiers under real-world conditions. The data sheets, for example, list parameters such as reverse recovery current vs di/dt, reverse recovery time vs junction temperature, typical peak forward recovery voltage vs di/dt, average forward current vs ambient temperature, and average forward current vs lead temperature. Such information is invaluable when you are maximizing rectifier performance under tough environmental conditions.

HV Plus rectifiers are available in two axial-leaded package sizes. The industrial-grade devices feature an operating range of -55 to +150°C, and 600V units cost \$1.60 for 2A versions and \$1.86 for 4A versions. The military-grade rectifiers operate over a range of -65 to +175°C; 600V units are priced at \$3.60 and \$5.50 for the 2 and 4A versions, respectively. (1000).

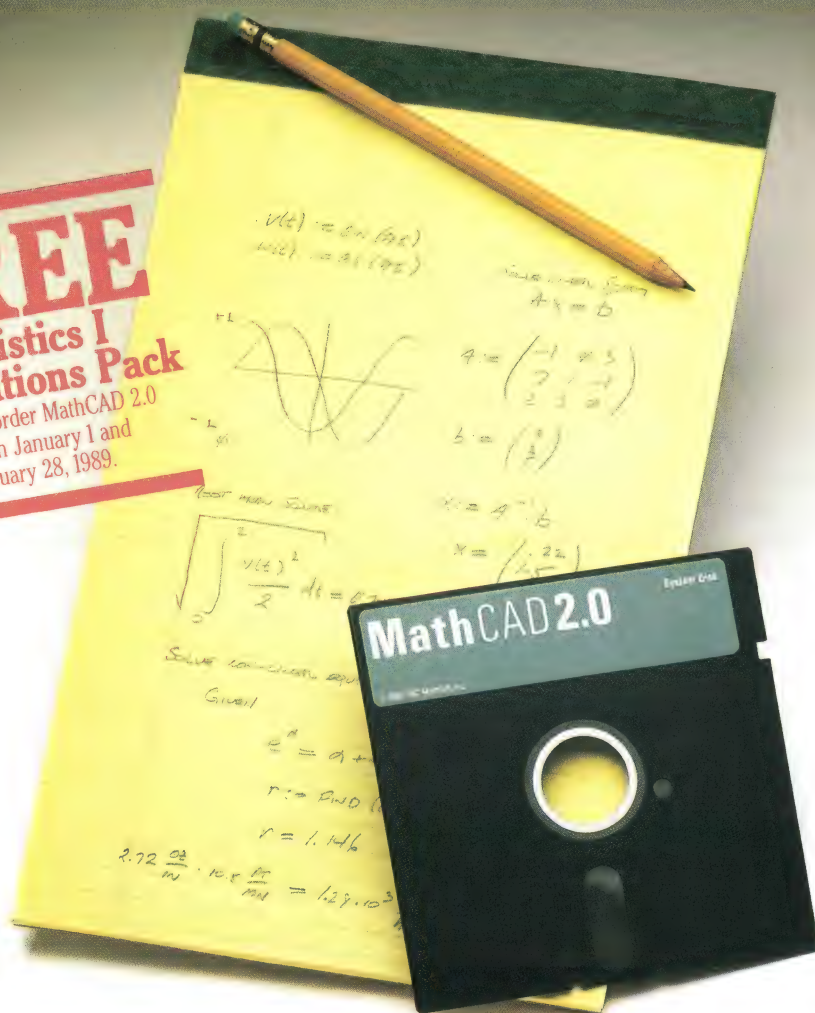
—Tom Ormond

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Circle No 731



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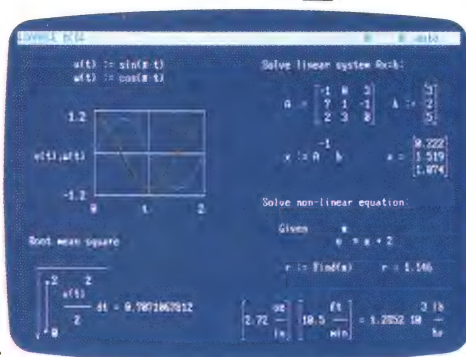
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# READERS' CHOICE

Of all the new products covered in EDN's **September 1, 1988**, issue, the ones reprinted here generated the most reader requests for additional information. If you missed them the first time, find out what makes them special: Just circle the appropriate numbers on the Information Retrieval Service card, use EDN's Express Request service, or refer to the indicated pages in our **September 1, 1988**, issue.

## HANDHELD DMM/SCOPE

The Model 200 portable 2½-lb DMM/oscilloscope provides dual-channel operation. It samples at 3M samples/sec max and offers autoranging (pg 232).

**Leader Instruments Corp.**

**Circle No 605**

## ENCODERS

Softpot Models SPM-50 and SPM-100 optical shaft encoders convert shaft angle, speed, and direction into real-time digital information (pg 226).

**US Digital Corp.**

**Circle No 603**

## MEASURING UNIT

The UDM-RMU (remote measurement unit) distance-measuring device communicates with a controller over an RS-232C link (pg 217).

**Contaq Technologies Corp.**

**Circle No 601**

## SIMULATOR

Extend is a modular, behavioral-simulation program that runs on Apple's Mac II, Mac SE, and Mac Plus computers. It lets you build block diagrams, insert the function of each block in the form of a script, and then connect the blocks together to form a system model (pg 228).

**Imagine That!**

**Circle No 604**

## WATCHDOG IC

The H6060 can act as a power supply monitor or as a reset generator for  $\mu$ P systems by incorporating voltage comparators, a programmable timer, and reset sequencing logic (pg 220).

**EM Microelectronic-Marin SA.**

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# VME Dream Card

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SERIES

# VIVISUN 2000™



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# LEAD TIME INDEX

Percentage of respondents

| ITEM                          | Off the shelf | 1-5 weeks | 6-10 weeks | 11-20 weeks | 21-30 weeks | Over 30 weeks | Average (weeks) | Last month's average (weeks) |
|-------------------------------|---------------|-----------|------------|-------------|-------------|---------------|-----------------|------------------------------|
| <b>TRANSFORMERS</b>           |               |           |            |             |             |               |                 |                              |
| Autotransformer               | 7             | 15        | 64         | 14          | 0           | 0             | 7.7             | 8.2                          |
| Isolated-Core                 | 8             | 15        | 46         | 31          | 0           | 0             | 8.9             | 11.5                         |
| Power transformer (power)     | 10            | 50        | 25         | 15          | 0           | 0             | 5.8             | 8.5                          |
| <b>CONNECTORS</b>             |               |           |            |             |             |               |                 |                              |
| Connecter panel               | 0             | 44        | 33         | 23          | 0           | 0             | 7.5             | 9.6                          |
| Flat/Cable                    | 25            | 45        | 20         | 10          | 0           | 0             | 4.4             | 4.2                          |
| Multi-pin circular            | 14            | 36        | 36         | 14          | 0           | 0             | 6.1             | 9.7                          |
| D-sub (2-piece)               | 21            | 43        | 29         | 7           | 0           | 0             | 4.6             | 7.3                          |
| F/Coaxial                     | 18            | 58        | 18         | 6           | 0           | 0             | 4.1             | 7.4                          |
| Socket                        | 15            | 60        | 20         | 5           | 0           | 0             | 4.1             | 3.8                          |
| Terminal blocks               | 29            | 47        | 18         | 6           | 0           | 0             | 3.7             | 4.8                          |
| Edge card                     | 13            | 33        | 47         | 7           | 0           | 0             | 5.8             | 5.9                          |
| Subminiature                  | 27            | 36        | 27         | 10          | 0           | 0             | 4.7             | 4.1                          |
| Back & panel                  | 15            | 46        | 31         | 8           | 0           | 0             | 5.1             | 8.1                          |
| Power                         | 13            | 40        | 27         | 13          | 7           | 0             | 7.1             | 6.0                          |
| <b>PRINTED CIRCUIT BOARDS</b> |               |           |            |             |             |               |                 |                              |
| Single sided                  | 0             | 65        | 35         | 0           | 0           | 0             | 4.7             | 5.3                          |
| Double sided                  | 0             | 59        | 36         | 5           | 0           | 0             | 5.4             | 6.2                          |
| Multi-layer                   | 0             | 26        | 63         | 6           | 5           | 0             | 8.0             | 6.8                          |
| Prototype                     | 0             | 87        | 9          | 4           | 0           | 0             | 3.9             | 3.4                          |
| <b>RESISTORS</b>              |               |           |            |             |             |               |                 |                              |
| Carbon film                   | 24            | 37        | 29         | 10          | 0           | 0             | 4.9             | 3.4                          |
| Carbon composition            | 32            | 36        | 32         | 0           | 0           | 0             | 3.6             | 3.8                          |
| Metal film                    | 19            | 48        | 33         | 0           | 0           | 0             | 4.0             | 4.1                          |
| Metal oxide                   | 23            | 39        | 38         | 0           | 0           | 0             | 4.2             | 4.9                          |
| Wirewound                     | 35            | 24        | 35         | 6           | 0           | 0             | 4.4             | 5.2                          |
| Potentiometers                | 13            | 50        | 33         | 4           | 0           | 0             | 4.7             | 5.2                          |
| Networks                      | 21            | 47        | 26         | 6           | 0           | 0             | 4.4             | 4.3                          |
| <b>USES</b>                   |               |           |            |             |             |               |                 |                              |
|                               | 56            | 27        | 11         | 6           | 0           | 0             | 2.6             | 2.2                          |
| <b>SWITCHES</b>               |               |           |            |             |             |               |                 |                              |
| Pushbutton                    | 22            | 39        | 30         | 9           | 0           | 0             | 4.9             | 4.5                          |
| Rotary                        | 6             | 53        | 29         | 12          | 0           | 0             | 5.7             | 7.8                          |
| Toggle                        | 21            | 32        | 36         | 11          | 0           | 0             | 5.5             | 5.8                          |
| Thumbwheel                    | 0             | 56        | 31         | 13          | 0           | 0             | 6.1             | 9.0                          |
| Snap action                   | 7             | 29        | 57         | 7           | 0           | 0             | 6.5             | 7.3                          |
| Momentary                     | 14            | 43        | 36         | 7           | 0           | 0             | 5.2             | 5.7                          |
| Equal-in-line                 | 14            | 50        | 29         | 7           | 0           | 0             | 4.9             | 6.2                          |
| <b>WIRE AND CABLE</b>         |               |           |            |             |             |               |                 |                              |
| Coaxial                       | 29            | 47        | 19         | 5           | 0           | 0             | 3.7             | 4.0                          |
| Flat ribbon                   | 35            | 43        | 22         | 0           | 0           | 0             | 3.0             | 3.3                          |
| Multiconductor                | 41            | 27        | 27         | 5           | 0           | 0             | 3.7             | 4.3                          |
| Hookup                        | 50            | 31        | 19         | 0           | 0           | 0             | 2.4             | 3.0                          |
| Wirewrap                      | 38            | 31        | 31         | 0           | 0           | 0             | 3.4             | 3.7                          |
| Power cords                   | 38            | 29        | 25         | 8           | 0           | 0             | 4.1             | 4.2                          |
| <b>POWER SUPPLIES</b>         |               |           |            |             |             |               |                 |                              |
| Switcher                      | 8             | 30        | 31         | 31          | 0           | 0             | 8.1             | 8.6                          |
| Linear                        | 7             | 27        | 39         | 27          | 0           | 0             | 8.1             | 6.1                          |
| <b>CIRCUIT BREAKERS</b>       |               |           |            |             |             |               |                 |                              |
|                               | 23            | 38        | 23         | 16          | 0           | 0             | 5.4             | 7.9                          |
| <b>HEAT SINKS</b>             |               |           |            |             |             |               |                 |                              |
|                               | 24            | 46        | 24         | 6           | 0           | 0             | 4.2             | 4.5                          |
| <b>BATTERIES</b>              |               |           |            |             |             |               |                 |                              |
| Lithium coin cells            | 15            | 38        | 38         | 9           | 0           | 0             | 5.5             | 7.0                          |
| NiCd alkaline                 | 40            | 40        | 20         | 0           | 0           | 0             | 2.8             | 3.4                          |
| Real-time clock back-up       | 30            | 40        | 30         | 0           | 0           | 0             | 3.6             | 7.4                          |
| <b>RELAYS</b>                 |               |           |            |             |             |               |                 |                              |
| General purpose               | 43            | 28        | 19         | 10          | 0           | 0             | 3.9             | 6.6                          |
| Control board                 | 30            | 45        | 5          | 20          | 0           | 0             | 4.8             | 7.3                          |

| ITEM                                | Off the shelf | 1-5 weeks | 6-10 weeks | 11-20 weeks | 21-30 weeks | Over 30 weeks | Average (weeks) | Last month's average (weeks) |
|-------------------------------------|---------------|-----------|------------|-------------|-------------|---------------|-----------------|------------------------------|
| <b>DISCRETE SEMICONDUCTORS</b>      |               |           |            |             |             |               |                 |                              |
| Dry reed                            | 0             | 64        | 9          | 27          | 0           | 0             | 6.8             |                              |
| Mercury                             | 14            | 57        | 0          | 15          | 14          | 0             | 7.6             |                              |
| Solid state                         | 39            | 38        | 6          | 17          | 0           | 0             | 4.2             |                              |
| <b>INTEGRATED CIRCUITS, DIGITAL</b> |               |           |            |             |             |               |                 |                              |
| Diode                               | 42            | 23        | 19         | 16          | 0           | 0             | 4.6             |                              |
| Zener                               | 36            | 28        | 16         | 20          | 0           | 0             | 5.2             |                              |
| Thyristor                           | 19            | 37        | 19         | 25          | 0           | 0             | 6.5             |                              |
| Small signal transistor             | 26            | 42        | 16         | 16          | 0           | 0             | 5.0             |                              |
| MOSFET                              | 14            | 43        | 14         | 29          | 0           | 0             | 6.9             |                              |
| Power, bipolar                      | 33            | 42        | 8          | 17          | 0           | 0             | 4.5             |                              |
| <b>INTEGRATED CIRCUITS, LINEAR</b>  |               |           |            |             |             |               |                 |                              |
| Communication/Circuit               | 29            | 36        | 21         | 14          | 0           | 0             | 4.9             |                              |
| OP amplifier                        | 29            | 29        | 29         | 13          | 0           | 0             | 5.2             |                              |
| Voltage regulator                   | 40            | 35        | 10         | 15          | 0           | 0             | 4.1             |                              |
| <b>MEMORY CIRCUITS</b>              |               |           |            |             |             |               |                 |                              |
| DRAM 16K                            | 22            | 44        | 0          | 22          | 12          | 0             | 7.7             |                              |
| DRAM 64K                            | 11            | 56        | 0          | 22          | 11          | 0             | 7.8             |                              |
| DRAM 256K                           | 8             | 25        | 17         | 33          | 17          | 0             | 11.5            |                              |
| DRAM 1M-bit                         | 0             | 20        | 40         | 30          | 0           | 10            | 11.5            |                              |
| SRAM 4K x 8                         | 0             | 13        | 25         | 62          | 0           | 0             | 11.9            |                              |
| SRAM 8K x 8                         | 6             | 12        | 12         | 46          | 12          | 12            | 15.2            |                              |
| SRAM 2K x 8                         | 14            | 15        | 14         | 57          | 0           | 0             | 10.4            |                              |
| ROM/PROM                            | 8             | 50        | 9          | 33          | 0           | 0             | 7.3             |                              |
| EPROM 64K                           | 29            | 7         | 35         | 29          | 0           | 0             | 7.5             |                              |
| EPROM 256K                          | 25            | 9         | 33         | 33          | 0           | 0             | 8.0             |                              |
| EPROM 1M-bit                        | 0             | 38        | 13         | 49          | 0           | 0             | 9.7             |                              |
| EEPROM 16K                          | 10            | 20        | 20         | 50          | 0           | 0             | 9.9             |                              |
| EEPROM 64K                          | 18            | 27        | 19         | 36          | 0           | 0             | 7.9             |                              |
| <b>DISPLAYS</b>                     |               |           |            |             |             |               |                 |                              |
| Panel meters                        | 20            | 27        | 33         | 13          | 7           | 0             | 7.2             |                              |
| Fluorescent                         | 11            | 23        | 33         | 33          | 0           | 0             | 8.4             |                              |
| CRT 12-inch monochrome              | 8             | 42        | 17         | 33          | 0           | 0             | 7.7             |                              |
| LED                                 | 37            | 31        | 16         | 16          | 0           | 0             | 4.6             |                              |
| Liquid crystal                      | 8             | 23        | 38         | 31          | 0           | 0             | 8.5             |                              |
| <b>MICROPROCESSOR ICs</b>           |               |           |            |             |             |               |                 |                              |
| 8-bit                               | 13            | 31        | 13         | 43          | 0           | 0             | 8.6             |                              |
| 16-bit                              | 0             | 40        | 20         | 40          | 0           | 0             | 8.9             |                              |
| 32-bit                              | 11            | 23        | 22         | 44          | 0           | 0             | 9.2             |                              |
| <b>FUNCTION PACKAGES</b>            |               |           |            |             |             |               |                 |                              |
| Amplifier                           | 23            | 16        | 38         | 23          | 0           | 0             | 7.0             |                              |
| Converter, analog to digital        | 7             | 14        | 43         | 36          | 0           | 0             | 9.4             |                              |
| Converter, digital to analog        | 8             | 17        | 42         | 33          | 0           | 0             | 8.9             |                              |
| <b>LINE FILTERS</b>                 |               |           |            |             |             |               |                 |                              |
|                                     | 25            | 13        | 25         | 37          | 0           | 0             | 8.1             |                              |
| <b>CAPACITORS</b>                   |               |           |            |             |             |               |                 |                              |
| Ceramic monolithic                  | 32            | 31        | 23         | 14          | 0           | 0             | 4.9             |                              |
| Ceramic disc                        | 36            | 19        | 27         | 18          | 0           | 0             | 5.5             |                              |
| Film                                | 30            | 30        | 20         | 20          | 0           | 0             | 5.5             |                              |
| Aluminum electrolytic               | 28            | 32        | 24         | 16          | 0           | 0             | 5.3             |                              |
| Tantalum                            | 31            | 31        | 19         | 19          | 0           | 0             | 5.3             |                              |
| <b>INDUCTORS</b>                    |               |           |            |             |             |               |                 |                              |
|                                     | 0             | 43        | 44         | 13          | 0           | 0             | 6.8             |                              |

Source: Electronics Purchasing Magazine's survey of buyers



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CIRCLE NO 92





# Speech-recognition products

*Long the dream of the data-entry operator, true speech recognition is on its way to becoming a reality. Commercially available products operate with a high degree of accuracy in many acoustically noisy environments.*

**John A Gallant, Associate Editor**

Since the first introduction of speech-recognition products in the early 1970s, computer operators have envisioned a system that could reliably recognize continuous speech without requiring any prior training. By definition, such a system would also be able to operate in the presence of background noise and over narrow-band communication channels such as the PSTN (Public Switched Telephone Network). Although the ideal system remains in the distant future, today's speech-recognition products can handle many data-entry applications with a high degree of flexibility and reliability.

Much R&D work is being done in the area of speech recognition. AT&T and IBM, for instance, are investing a lot of time and money into the technology. Not

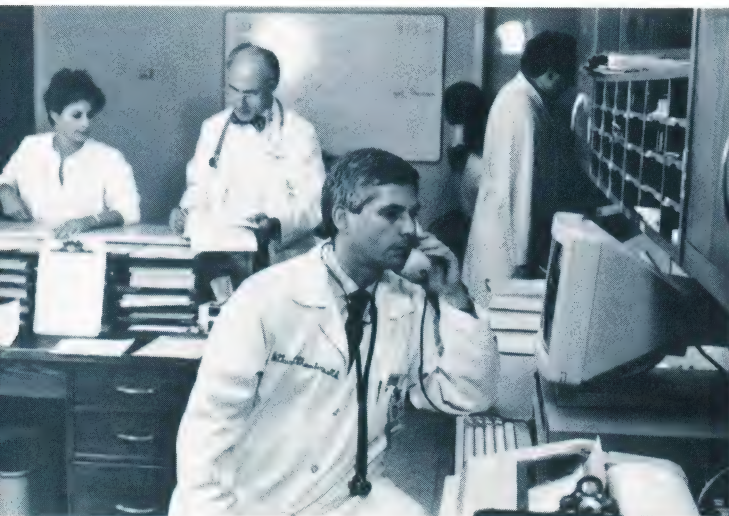
surprisingly, the universities are also experimenting with speech recognition. Commercially available products, are, however, for the time being, few and far between. Nonetheless, the products that are on the market *do* bear scrutiny.

Commercially available speech-recognition products fall into two broad categories: speaker (operator) dependent and speaker independent. Speaker-dependent products require that an operator train them before they can identify words or utterances. Speaker-independent products can understand speakers with different accents and speech patterns without any operator training. The penalty usually paid for speaker independence is a total-recognition vocabulary having a smaller active vocabulary.

The total-recognition vocabulary is the complete set of words and phrases that a speech-recognition system can recognize. The active vocabulary is a subset of the total-recognition vocabulary and consists of the maximum number of words a system can simultaneously recognize at a given time. Many speech-recognition devices let the developer select a grammar for customized applications. The grammar determines which subset of the total vocabulary is active at a particular time based on a trigger-phrase command or the syntax of words in a sentence. Depending on the manufacturer, you'll find an enormous difference between the total-recognition vocabulary of a product and its actual active vocabulary (**Table 1**).

Regardless of the category—speaker dependent or

*Relying entirely on vocal data entry, a doctor can dictate reports directly into Kurzweil's VoiceEM system, edit them on the computer screen, and order an instant printout.*



*Although the talking typewriter is years away, some speech recognition products on the market today can interpret conversational patterns of speech for data-entry applications. (Photo courtesy Verber Voice Systems)*







*Although the ideal system remains in the distant future, today's speech-recognition products can handle many data-entry applications.*

---



**Isolated-word speech-recognition systems** such as the Voicescribe 1000 from Cherry Electrical Products require a 200-msec pause between utterances to recognize words.

speaker independent—speech-recognition products use one of two methodologies: isolated-word recognition or continuous-word recognition. Isolated-word speech-recognition products require a pause between utterances; the pause must last for 200 msec or more. An utterance can be a single word or a multiword phrase lasting for a few seconds. Continuous-word speech-recognition products can understand complete sentences and phrases connected together just as they are in everyday speech.

#### **Dependent systems recognize one operator only**

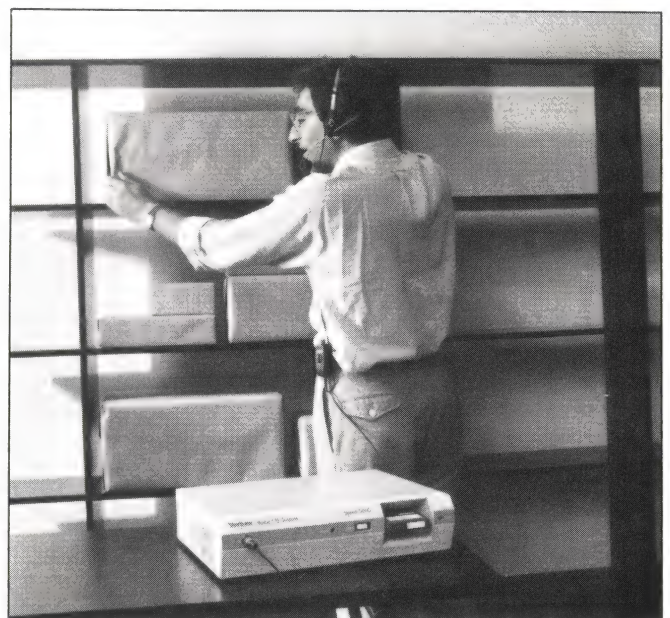
Dragon Systems's Voicescribe 1000 is a representative speaker-dependent system that uses isolated-word recognition. It costs \$1595. (Cherry Electrical Products Corp also has a licensing agreement to sell the product.) The system's hardware consists of an A/D plug-in card for the IBM PC/XT or PC/AT and a Shure headset microphone for training the system. The computer does the prompting as you train, or "enroll," the system by repeating an isolated word four or five times. Using a stochastic processing technique, the software develops word models from the sampled speech and stores the models in a vocabulary file. The software lets the user specify a grammar, which improves the system's recognition performance by limiting the number of legally active vocabulary words for a particular syntax.

When running on an IBM PC/AT with 640k bytes of RAM, the Voicescribe 1000 has an active vocabulary

of 1000 words. When operating in an IBM PC/XT with 256k bytes of RAM, it recognizes 100 to 200 words. The system requires a minimum pause of 200 msec between each utterance to recognize the spoken text. A utility emulates a keyboard by passing an output string associated with a recognized word to an application running on the host. This speech-to-text-conversion function, for example, can recognize and pass the word "copy" as an ASCII "C" to a program running under Lotus 1-2-3.

Dragon Systems also offers two other products, the Dragonwriter-1000 and -5000, that capitalize on the technology used to produce the Voicescribe system. Unlike their predecessor, however, the Dragonwriter boards are natural-language speech-recognition systems and do not require a customized grammar to identify words in a large vocabulary. A computer operator can dictate to these systems using this "free text" in an isolated-word recognition mode.

The Dragonwriter products are intended for the IBM PC family of computers and incorporate a Texas Instruments' TMS320 DSP chip. The Dragonwriter-1000 can understand vocabularies having more than 1000 active words. The Dragonwriter-5000 is currently undergoing beta testing and has a total-recognition—and active—vocabulary of 5000 words of free text. The company recommends that, in order for a Dragonwriter system



**Designed for data entry** in environments where both a person's hands and eyes are busy, the Verbex Voice Activated Package Handling System can understand conversational speech.



to operate in real time, the host should have a 12-MHz (at least) 80286 or 80386  $\mu$ P, 2M bytes of RAM (including LIM expanded memory), and a 40M-byte or larger hard-disk drive. Each board costs \$4500.

### More isolated-word speech-recognition products

Kurzweil Applied Intelligence Inc also offers a speaker-dependent product that uses isolated-word recognition. The base system, or development package, sells for \$12,900 and consists of an IBM PC/AT plug-in board, recognition software, and a knowledge-based editor. The system needs a host with an 80386  $\mu$ P, 6M to 10M bytes of RAM, an 80387 coprocessor, and a 40M-byte hard-disk drive. For \$21,900, you can purchase the system with an 80386 host computer.

The Kurzweil system can identify as many as 5000 active utterances; you can either have the company supply the vocabulary or you can create your own. A 800-msec pause is required between each utterance. The system identifies words using a syntax that operates on the most probable English word order, the phonetic structure, and the acoustics of each vocalization.

In addition to the development system, the company offers three turnkey speech-recognition packages for generating medical reports: VoiceRAD, VoiceEM, and VoicePATH. Each costs \$3000. The packages rely on trigger phrases to display a predefined report segment on a monitor screen. These segments provide the operator with a fill-in-the-blank capability. For example, if an operator prompts the system with "clinical suspicion," a message on the display responds by asking the operator to specify the position and probable diagnosis, such as "left or right mammary" and "diffuse nodularity."

### Spoken commands supplement keyboard entry

The Vocalink Speech Recognition Board from International Voice Products is a different type of speaker-dependent, isolated-word speech-recognition system. The board contains 128k bytes of onboard memory for storing word models and recognition software, and it therefore doesn't occupy any of the host's (IBM PC/XT or PC/AT) memory.

You have to enroll the system by repeating a word or a phrase three to five times before the system can recognize a command, which can last as long as 2.5 sec. The board supplements keyboard inputs by converting as many as 240 vocal commands into ASCII strings for the simulation of keystrokes. For instance,



*Some speaker-dependent speech-recognition systems accommodate cellular-phone applications. A good example is the Vocalink family from International Voice Products.*

an operator using a word processor can use the keyboard to enter text and a microphone to input commands such as "Indent," "Bold," or "Column Three." A 250-msec pause is necessary between instructions. The Vocalink Speech Recognition Board sells for \$1295.

Although you may be leery of using such expensive products—especially if your data-entry application is one that demands low cost—less-expensive speech-recognition products are available. International Voice Products, for instance, offers its Vocalink Speech Recognition Board without onboard memory for \$395. The half-size board requires a host with at least 256k bytes of main memory and recognizes 100 active commands out of 400.

Covox offers an even less-expensive speech-recognition system, the Voice Master Key, for \$130. The hardware consists of an IBM PC/XT- or PC/AT-compatible plug-in board with a pre-amplifier, an 8-bit A/D converter, and an electret microphone. Like the International Voice Product offering, the Voice Master Key software requires a host with 256k bytes of main memory. It recognizes a maximum of 64 speaker-trained isolated-word commands.

### Conversational speech is possible, too

Isolated-word speech-recognition systems are efficient for many data-entry applications that require an operator's hands and eyes to be busy. Unfortunately, there is a certain unnaturalness about them. Because ordinary conversation doesn't require pauses between

*Text continued on pg 118*



**TABLE 1—REPRESENTATIVE SPEECH-RECOGNITION PRODUCTS**

| COMPANY                                | PRODUCT                              | STAND-ALONE<br>SYSTEM | SUBSYSTEM FOR<br>A HOST COMPUTER | PLUG-IN<br>BOARD                      | SPEAKER<br>DEPENDENT | SPEAKER<br>INDEPENDENT | REGOGNITION       |                    | MEMORY<br>REQUIREMENT                                            | VOCABULARY |                       |
|----------------------------------------|--------------------------------------|-----------------------|----------------------------------|---------------------------------------|----------------------|------------------------|-------------------|--------------------|------------------------------------------------------------------|------------|-----------------------|
|                                        |                                      |                       |                                  |                                       |                      |                        | ISOLATED<br>WORDS | CONNECTED<br>WORDS |                                                                  | ACTIVE     | TOTAL<br>RECOGNITION  |
| CHERRY<br>ELECTRICAL<br>PRODUCTS*      | VOICESCRIBE<br>1000                  |                       |                                  | IBM<br>PC/<br>XT/<br>AT               | X                    |                        | X                 |                    | 640k BYTES                                                       | 1000       | 1000                  |
|                                        |                                      |                       |                                  |                                       |                      |                        |                   |                    | 256k BYTES                                                       | 200        | 200                   |
| COVOX<br>SYSTEMS                       | VOICE MASTER<br>KEY                  |                       |                                  | IBM<br>PC/<br>XT/<br>AT               | X                    |                        | X                 |                    | 256k BYTES                                                       | 64         | 64                    |
| DRAGON<br>SYSTEMS                      | DRAGONWRITER-<br>1000                |                       |                                  | IBM<br>PC/<br>XT/<br>AT               | X                    |                        | X                 |                    |                                                                  | >1000      | >1000                 |
|                                        | DRAGONWRITER-<br>5000                |                       |                                  | IBM<br>PC/<br>XT/<br>AT               | X                    |                        | X                 |                    |                                                                  | 5000       | 5000                  |
| INTERNATIONAL<br>VOICE<br>PRODUCTS     | VOCALINK<br>RECOGNITION<br>BOARD**   |                       |                                  | IBM<br>PC/<br>XT/<br>AT               | X                    |                        | X                 |                    | 64k BYTES                                                        | 100        | 400                   |
|                                        | VOCALINK 4000                        | X                     |                                  | IBM<br>PC/<br>XT/<br>AT               | X                    |                        |                   | X                  | 256k BYTES<br>IN IBM PC                                          | 100        | 200                   |
|                                        |                                      |                       |                                  | DEC<br>VAX                            |                      |                        |                   |                    | 512k BYTES<br>IN DEC VAX                                         |            |                       |
|                                        | VOCALINK<br>SYS 300                  | X                     |                                  |                                       | X                    |                        | X                 |                    | SELF-<br>CONTAINED                                               | 100        | 200                   |
|                                        | VOCALINK<br>CELLULAR VOICE<br>DIALER | X                     |                                  |                                       | X                    |                        | X                 |                    | N/A                                                              | 40         | 40                    |
| KURZWEIL<br>ARTIFICIAL<br>INTELLIGENCE | VOICERAD AND<br>VOICEEM              | X                     |                                  |                                       | X                    |                        | X                 |                    | MINIMUM OF<br>10M BYTES OF<br>DISK STORAGE                       | 5000       | 5000                  |
| SCOTT<br>INSTRUMENTS                   | SIR MODEL 20                         |                       |                                  | IBM<br>PC/<br>XT/<br>AT               |                      | X                      | X                 |                    | ALL RECOGNI-<br>TION SOFTWARE<br>AND WORD<br>STORAGE ON<br>BOARD | 75         | 200                   |
| SPEECH<br>SYSTEMS INC                  | DS200<br>DEVELOPMENT<br>SYSTEM       | X                     |                                  |                                       |                      |                        |                   | X                  | SELF-<br>CONTAINED                                               | 3000       | 35,000                |
| TEXAS<br>INSTRUMENTS                   | TI-SPEECH<br>SYSTEM                  |                       |                                  | IBM<br>PC/<br>XT/<br>AT               | X                    |                        | X                 | X                  | 256k BYTES;<br>DUAL FLOPPY-<br>DISK DRIVES                       | 50         | 50                    |
|                                        |                                      |                       |                                  | TI's<br>PCs                           |                      |                        |                   |                    |                                                                  |            |                       |
| VERBEX<br>VOICE<br>SYSTEMS             | SERIES 5000                          | X                     | X                                |                                       | X                    |                        |                   | X                  | N/A                                                              | 100        | 100 (600<br>OPTIONAL) |
| VOICE<br>CONTROL<br>SYSTEMS            | VOICE-GATEWAY                        | X                     |                                  |                                       |                      | X                      | X                 |                    | SELF-<br>CONTAINED                                               | 40         | 40                    |
|                                        | TELEREC                              |                       |                                  | IBM<br>PC/<br>XT/<br>AT               |                      | X                      | X                 |                    | N/S                                                              | 16         | 16                    |
|                                        | VCS1000                              |                       | X                                |                                       |                      | X                      | X                 |                    | N/S                                                              | 17         | 36                    |
| VOICE<br>PROCESSING<br>SYSTEMS         | VPC1000                              |                       |                                  | IBM<br>PC/<br>XT/<br>AT<br>2ND<br>QTR |                      | X                      |                   | X                  | N/S                                                              | 13         | 13                    |

\*CHERRY HAS SIGNED A LICENSING AGREEMENT WITH DRAGON SYSTEMS TO MANUFACTURE THE VOICESCRIBE 1000.



|  | DIGITAL<br>SIGNAL<br>PROCESSOR | TELEPHONE<br>INTERFACE                              | TEXT-TO-<br>SPEECH<br>CONVERSION<br>FUNCTION | PRICE                                                                 | FEATURES                                                                                                                                                                           |
|--|--------------------------------|-----------------------------------------------------|----------------------------------------------|-----------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|  | N/A                            | NO                                                  | OPTIONAL                                     | \$1595                                                                | MICROPHONE, 8-BIT ADC, AND SOFTWARE FOR ISOLATED-WORD TRAINING AND RECOGNITION.                                                                                                    |
|  | N/A                            | NO                                                  | OPTIONAL                                     | \$130                                                                 | MICROPHONE, 8-BIT ADC, 5-KHz ANTIALIASING FILTER, DATA COMPRESSION, AND SOFTWARE FOR VOICE COMMAND TRAINING.                                                                       |
|  | TMS320                         | NO                                                  | OPTIONAL                                     | \$3600                                                                | MICROPHONE, ONBOARD SIGNAL PROCESSOR, AND SOFTWARE FOR ISOLATED-WORD TRAINING AND RECOGNITION USING FREE-TEXT DICTATION.                                                           |
|  | TMS320                         | NO                                                  | OPTIONAL                                     | \$4500                                                                | SAME AS DRAGONWRITER-1000.                                                                                                                                                         |
|  | ASIC                           | NO                                                  | NO                                           | \$1295                                                                | UNIDIRECTIONAL MICROPHONE, ONBOARD SIGNAL PROCESSOR, AND UTILITY PROGRAMS FOR TYING INTO WORDSTAR AND LOTUS 1-2-3.                                                                 |
|  | TMS320                         | NO                                                  | NO                                           | \$5200                                                                | VARIETY OF OPTIONAL MICROPHONES AND SOFTWARE FOR TRAINING AND RECOGNITION USING GRAMMAR AND SYNTAX; OPTIONAL VOICE CARTRIDGE.                                                      |
|  | ASIC                           | NO                                                  | NO                                           | \$1655                                                                | VARIETY OF OPTIONAL MICROPHONES; ENCLOSURE, POWER SUPPLY, CABLES, AND TRAINING AND RECOGNITION SOFTWARE.                                                                           |
|  | ASIC                           | YES                                                 | YES                                          | \$395                                                                 | LETS YOU PRONOUNCE DIGITS OR RECALL STORED NUMBERS BY SPEAKING "LABEL" OR "NAME" FOR THE NUMBER.                                                                                   |
|  | TMS320C25                      | NO                                                  | YES                                          | \$15,900 W/O A PC;<br>\$24,900 WITH AN<br>IBM 386 PC                  | PACKAGED SYSTEM FOR CREATING MEDICAL REPORTS; SYSTEM USES "TRIGGER PHRASES" TO ACTIVATE LEGALLY VALID WORDS.                                                                       |
|  | TMS320C25                      | OPTIONAL                                            | NO                                           | \$1495                                                                | SYSTEM USES AUTOCORRELATION TO RECOGNIZE SPEECH WITH VARYING TIMBRE; SYSTEM IS FIELD TRAINABLE.                                                                                    |
|  | MC56001                        | NO                                                  | YES                                          | \$49,500                                                              | SYSTEM RECOGNIZES PHONEMES FOR CONNECTED-WORD RECOGNITION.                                                                                                                         |
|  | TMS320C10                      | OPTIONAL<br>DAUGHTER<br>BOARD WITH<br>DTMF FUNCTION | YES                                          | \$1150; TOOLKIT<br>SOFTWARE, \$300;<br>DAUGHTER<br>BOARD, \$350       | STANDARD SYSTEM RECOGNIZES ISOLATED WORDS; TOOLKIT LETS THE SYSTEM RECOGNIZE CONNECTED SPEECH; UNIX AND XENIX SYSTEMS ON THE WAY.                                                  |
|  | N/S                            | NO                                                  | YES                                          | \$6950 FOR<br>DEVELOPMENT<br>SYSTEM; \$5600<br>FOR PACKAGED<br>SYSTEM | TWO PACKAGED SYSTEMS INCLUDE A PACKAGE-HANDLING SYSTEM AND A MANUFACTURING CONTROL SYSTEM; DEVELOPMENT SYSTEM INCLUDES MICROPHONE AND TRAINING SOFTWARE. PERSONAL VOICE CARTRIDGE. |
|  | TMS320                         | YES                                                 | YES                                          | \$19,500                                                              | TURNKEY SYSTEM INCLUDES IBM PS/2 MODEL 50, 60, OR 80.                                                                                                                              |
|  | TMS320                         | YES                                                 | NO                                           | \$2495                                                                | IBM PC/XT AND PC/AT CARD AND DAUGHTER CARD OCCUPIES 2 SLOTS; COMMUNICATES WITH THE HOST VIA AN RS-232C INTERFACE OR PC BUS.                                                        |
|  | N/A                            | NO                                                  | YES                                          | \$1295                                                                | HEADSET MICROPHONE, ENCLOSURE, AND WALL-MOUNT POWER SUPPLY; COMMUNICATES WITH HOST VIA RS-232C INTERFACE.                                                                          |
|  | TMS320C25                      | YES                                                 | YES                                          | \$6500                                                                | SYSTEM RECOGNIZES CONTINUOUS SPEECH OVER THE PSTN; SOFTWARE PROMPTS THE USER TO "FILL IN THE BLANKS."                                                                              |

\*\*A VERSION WITHOUT ONBOARD MEMORY IS AVAILABLE FOR \$395. N/A = NOT APPLICABLE N/S = NOT SPECIFIED



*Commercially available speech-recognition products fall into two broad categories: speaker dependent and speaker independent.*

---

utterances, some operators find this restriction annoying and have trouble becoming accustomed to it. The ability to recognize connected speech is admittedly more difficult than isolated-word recognition, but you do have several choices if you want to use this type of product in your application (**Table 1**).

Verbex Voice Systems' Series 5000, for instance, is a speaker-dependent system that can recognize words and utterances connected together in a natural-speaking manner from an active vocabulary of 100 words. Although the standard total-recognition vocabulary is also 100, a 600-word total-recognition vocabulary is optional.

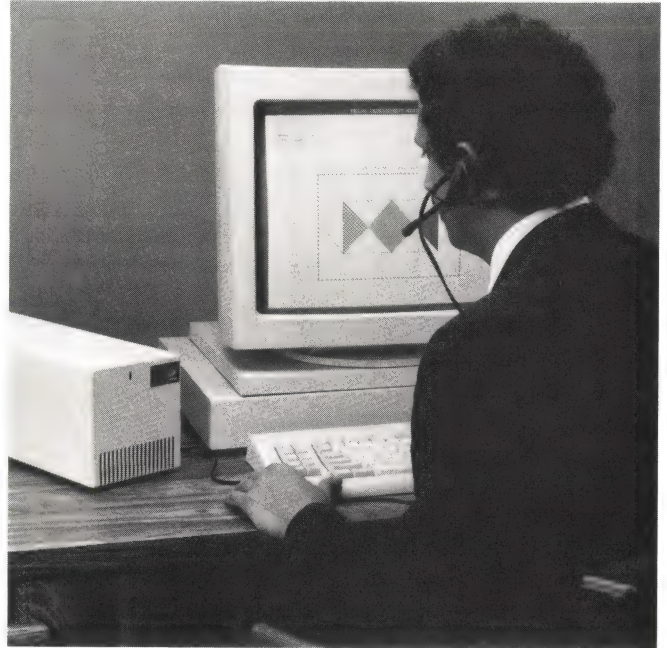
The stand-alone subsystem connects to a host that runs a software package called Voiceware. The subsystem and software costs \$6950. The software provides the user with a grammar, a vocabulary, and training scripts. An optional Voice Developer package (\$600) lets you enroll your own vocabulary by vocalizing a word or a short phrase several times in a manner similar to the isolated-word models.

The Series 5000 uses co-articulation rules (**Ref 1**) to recognize connected speech. For example, the feature-recognition characteristics for the number 7 are different for the number 745 than for 457. To aid in the process of recognizing varying voice patterns, the training scripts in the Voiceware package contain a number of samples of connected speech patterns. The development software accounts for different speech patterns by letting the operator enroll a training script that is representative of all the expected combination of words. The system also retrain a voice template each time a word is spoken to adapt to the changes in a user's voice over time due to fatigue.

Verbex offers two turnkey software packages for the Series 5000: the Package Handling System for shipping, receiving, stockroom, and mailroom environments, and the Manufacturing Control System for production, quality-control, and materials-handling environments. Each package costs \$5600.

#### **Many products use DSP algorithms**

The TI-Speech System from Texas Instruments is a speaker-dependent, isolated-word speech-recognition system that optionally can recognize continuous speech. The hardware is compatible with the IBM PC/XT and PC/AT and TI's Professional Computer family and consists of a plug-in speech board, a microphone, and a speaker for verification. The board uses a TMS320 DSP chip to perform linear-predictive-coding



*Using a 35,000-word dictionary and co-articulation rules, the DS200 Speech Input Development System from Speech Systems Inc recognizes speaker-independent continuous speech.*

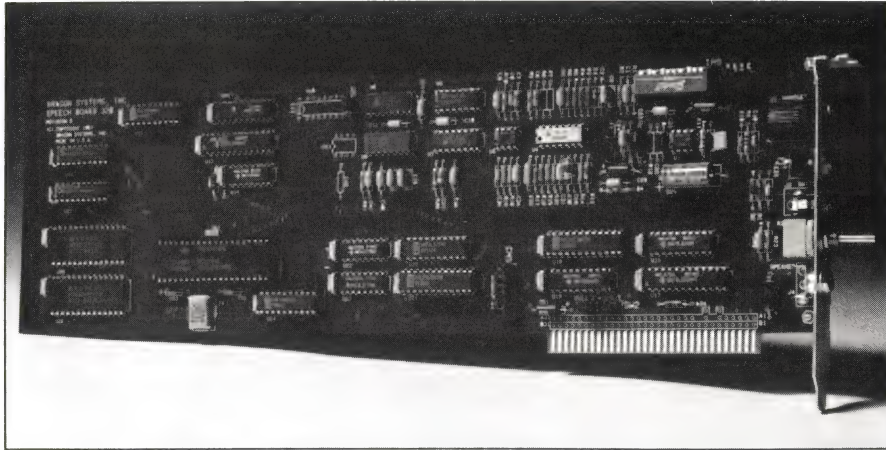
(LPC) and dynamic-time-warping (DTW) algorithms on the sampled speech. DTW is a technique that normalizes the varying lengths of time a speaker takes to enter a particular phrase (**Ref 1**).

The standard isolated-word recognition software recognizes as many as 50 words and converts them into an ASCII string for text-to-speech verification. A transparent keyboard package translates a recognized command to a keystroke sequence and transfers the information to an application running MS-DOS.

The optional toolkit package provides the software for identifying connected speech. First, the operator has to determine the set of words and sentences for a particular application. Then, he has to create a text file to define which words come first and which ones follow, including all possible options—a monumental task, by all accounts. Finally, he has to train the system to recognize his voice.

The standard TI-Speech System costs \$1150 and requires a personal computer with 256k bytes of memory and dual disk drives. The toolkit software package costs an additional \$300. An optional add-on card, which costs \$350, lets the system receive messages over the telephone lines. In the second quarter, the company plans to offer a board for the IBM PC/XT and PC/AT that runs Unix and Xenix.





**Speaker-independent speech-recognition boards** like the Dragonwriter products from Dragon Systems can recognize isolated words in active vocabularies exceeding 1000 words.

Like the TI offering, the Vocalink System 4000 from International Voice Products uses a TMS320 DSP chip to identify speaker-dependent, continuous-word speech. Unlike the TI offering, it creates word models based on the frequency and amplitude of the sampled speech for a subsequent Markov-process analysis. The system creates a voice-recognition table for each user, which is stored on a personal voice cartridge. Each cartridge contains a grammar that recognizes 100 words (out of a total-recognition vocabulary of 200) as well as training scripts of samples for connected-word options.

The \$5200 stand-alone subsystem can attach to either an IBM PC or a DEC VAX. An IBM PC requires at least 256k bytes of memory and two 320k-byte disk drives. A VAX 730, 750, or 780 has to have a minimum of 512k bytes of memory.

### Independent products listen to different drummers

Although speaker-dependent speech-recognition systems are effective for many data-entry applications, the algorithms that they use do not mimic two peoples' voices—no matter how similar. The algorithms consist of matching a sampled speech pattern with a template created during the enrolling process. The speech-recognition system compares each sample of an utterance with all of the stored template data and assigns a number according to "best fitness." The highest accumulated best fitness score for all of the samples determines which of the stored utterances provides the closest match. The best fitness score for speaker-dependent systems is quite low when someone other than the trainer uses the system.

Some speaker-dependent systems achieve some measure of speaker independence by having a number

of speakers with varying speech patterns train the system with identical vocabularies. Although this approach is satisfactory for some applications, such a scheme can demand a significant amount of computer memory.

For those applications that call for complete speaker independence, several speech-recognition products are available that use algorithms different from their speaker-dependent counterparts. These algorithms recognize subword features (syllables, phonetics) to distinguish words in a limited vocabulary based on their acoustic or phonetic differences.

### Suitable for remote-processing applications

Voice Control Systems, for example, offers a plug-in module that occupies two card slots in an IBM PC/XT or PC/AT that can recognize speaker-independent speech over the PSTN. The \$2495 system recognizes 14 canned, isolated words arranged in three subvocabularies: (1) 1, 2, 3, 4, 5, 6, 7, 8, 9, 0, "oh" (for users not wishing to pronounce zero), help, cancel, terminate; (2) yes, no, help, cancel, terminate; (3) 1, 2, 3, 4, yes, no, help. The Telerec system is useful in remote-transaction-processing applications; the software prompts the user for a response over the phone lines. A trigger word or phrase establishes which subvocabulary is active at any given time. The telephone interface provides autoanswer, autodial, DTMF decoding and generation, and call-progress-monitoring capabilities. The Telerec system can reside in a passive backplane and communicate with the host through an RS-232C port.

Another product from Voice Control Systems, the VCS1000, is a speaker-independent stand-alone subsystem in a 8.5×1.5×5.75-in. cabinet that can recog-



*Some systems use trigger phrases to display predefined messages on a monitor screen.*

nize 36 canned, isolated words arranged in four subvocabularies. The VCS1000 comes with a Shure SM10 noise-cancelling headset for vocal data entry. It communicates with a host through an RS-232C interface and runs from a 100V ac wall-mount power supply. Some of the words that you can prompt the system to recognize are forward, up, down, on, off, left, right, and backward. For security-system applications, the Voice Sentry system recognizes the following words: help, police, fire, ambulance, intruder, rape, and neighbor. Both systems cost \$1295.

Voice Processing Corp has developed a technology that can recognize continuous, conversational speaker-independent speech over the PSTN. The VPC1000 technology separates speech into phonetic blocks and recognizes a 13 canned-word active vocabulary. It can recognize the digits 0 through 9, "oh," yes, and no in remote-transaction applications such as credit authorization, catalog sales, and inventory status. If a customer is asked for a credit-card number over the tele-

phone, for example, he can recite the number 765321 without pausing between digits.

The manufacturer currently leases its software technology to OEM computer manufacturers. It plans to have an IBM PC/XT- and PC/AT-compatible board for sale in the second quarter. The board will have an 80386  $\mu$ P and a TI TMS320C25 DSP chip for real-time processing. The board and accompanying software will cost approximately \$5000.

#### **Shakespeare only used a 29,066-word dictionary**

A much more expensive system is the DS200 Speech Input Development System from Speech Systems Inc. The \$49,500 speaker-independent, continuous-word speech-recognition system operates with a Sun 3 or 4 workstation having a minimum of 4M bytes of main memory and 13M bytes of disk-storage space for program storage. The system comes with a standard dictionary that contains the phonetic spellings, or pronunciations, of 35,000 English words. It also includes sev-

## **Manufacturers of speech-recognition products**

For more information on speech-recognition products such as those discussed in this article, contact the following manufacturers directly, circle the appropriate numbers on the Information Retrieval Service card, or use EDN's Express Request service.

**Cherry Electrical Products Inc**  
3600 Sunset Ave  
Waukegan, IL 60087  
(312) 360-3523  
Circle No 650

**Covox Inc**  
675 Conger St  
Eugene, OR 97402  
(503) 342-1272  
TLX 706017  
FAX 503-342-1283  
Circle No 651

**Dragon Systems Inc**  
Chapel Bridge Park  
90 Bridge St  
Newton, MA 02158  
(617) 965-5200  
FAX 617-527-0372  
Circle No 652

**International Voice Products Inc**  
14251-B Chambers Rd  
Tustin, CA 92680  
(714) 544-1711  
FAX 714-544-4045  
Circle No 653

**Kurzweil Applied Intelligence Inc**  
411 Waverly Oaks Rd  
Waltham, MA 02154  
(617) 893-5151  
TWX 910-380-9408  
Circle No 654

**Scott Instruments Corp**  
1111 Willow Springs Dr  
Denton, TX 76205  
(817) 387-9514  
FAX 817-566-3174  
Circle No 655

**Speech Systems Inc**  
18356 Oxnard St  
(818) 881-0885  
FAX 818-342-9851  
Circle No 656

**Texas Instruments Inc**  
Box 2909, MS 2243  
Austin, TX 78769  
(800) 527-3500  
(Demonstration: (512) 250-4114)  
Circle No 657

**Verbex Voice Systems Inc**  
185 Ridgedale Ave  
Cedar Knolls, NJ 07927  
(201) 267-7507  
FAX 201-267-0548  
Circle No 658

**The Voice Connection**  
17835 Skypark Circle, Suite C  
Irvine, CA 92714  
(714) 261-2366  
Circle No 659

**Voice Control Systems Inc**  
14140 Midway Rd, Suite 100  
Dallas, TX 75244  
(214) 386-0300  
FAX 214-386-5555  
Circle No 660

**Voice Processing Corp**  
1 Main St  
Cambridge, MA 02142  
(617) 494-0100  
Circle No 661

**Votan Inc**  
4487 Technology Dr  
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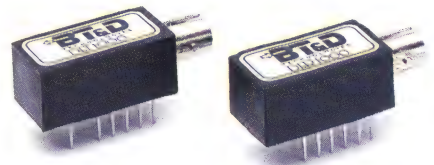
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*An operator using a word processor can use  
the keyboard to enter text and a microphone  
to input commands such as "Indent"  
or "Bold."*

---

eral generic male and female speaker models, which have varying pronunciations or dialects such as "data" or "dater." The system also provides the operator with the capability of developing new words using a training sequence.

The DS200 comes with an external subsystem, called the Phonetic Engine, that communicates with the host at 9600 baud over an RS-232C link. Before using the voice-input system, an operator must load the Phonetic Engine with an appropriate speaker model. The Phonetic Engine then accepts connected speech from an operator using a microphone to generate a string of phonetic codes to the host.

The resident software in the host lets you create a syntax to define which dictionary words should be active at a particular time. Deana Murchison, marketing communications manager for Speech Systems Inc, claims that developers have created vocabularies having as many as 3000 active words. The software uses the syntaxes and dictionary, along with several co-articulation rules, to recognize connected speech. The co-articulation rules ensure that expressions such as "did you" and "diyu" have equal candidacy.

#### **Field-trainable products are available**

All of the speech-recognition products discussed up to this point—notwithstanding the category or methodology—use algorithms that rely on the frequency parameters in a sampled speech waveform. They usually store templates containing frequency vectors generated by FFT, LPC, or Cepstrum analysis.

Scott Instruments Corp takes a markedly different approach. The company's SIR Model 20 comes with a template of utterances created by people with various accents and dialects to facilitate speaker-independent recognition. The recognition algorithm uses autocorrelation techniques to determine the best match between a waveform of an entire spoken phrase and the waveform of the nearest stored utterance.

The \$1495 SIR Model 20 consists of an IBM PC/XT- or PC/AT-compatible plug-in board and software that can recognize as many as 75 active speaker-independent isolated words from a total-recognition vocabulary of 200. Each utterance requires a 250-msec pause. All of the recognition templates and software are on the plug-in board so that the system doesn't occupy any of the host's main memory. It's also possible for an operator in the field to train the system.

Speaker-recognition products are not perfect, but neither are humans. All of the manufactures claim a recognition accuracy above 95%; some claim an accuracy greater than 99%. These statistics depend heavily on the application, the active vocabulary, and the background noise present in the environment. More importantly, the performance of speech-recognition products is constantly improving. Whereas products with 80% accuracy were typical three or four years ago, all of today's commercial manufacturers claim that accuracies in the low 90% region are unacceptable.

At present, commercially available speech-recognition systems operating in noisy factory or office environments can easily meet the OSHA requirements of 85 dB using noise-cancelling microphones and proprietary algorithms. You should also keep in mind that the performance of these products improves when the training process takes into account the background noise expected during normal operation. For the reader who wishes to investigate the techniques generally employed in speech recognition, **Ref 1** is an excellent source. Even though the talking typewriter is a number of years away, today's speech-recognition devices are providing realistic solutions for many data-entry problems. **EDN**

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#### **Reference**

1. Bristow Geoff, ed, *Electronic Speech Recognition*, McGraw-Hill Book Co, NY, NY, 1986, ISBN 0-07-007913-7.

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**Article Interest Quotient (Circle One)**  
**High 497 Medium 498 Low 499**



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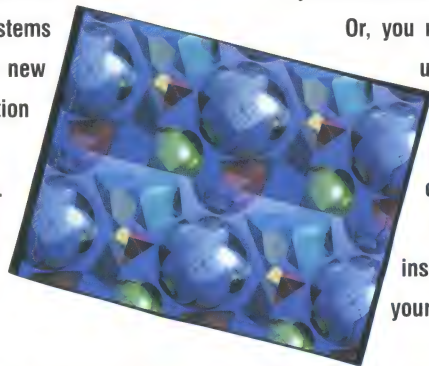
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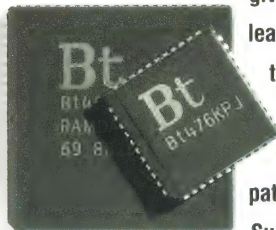
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Any Questions?

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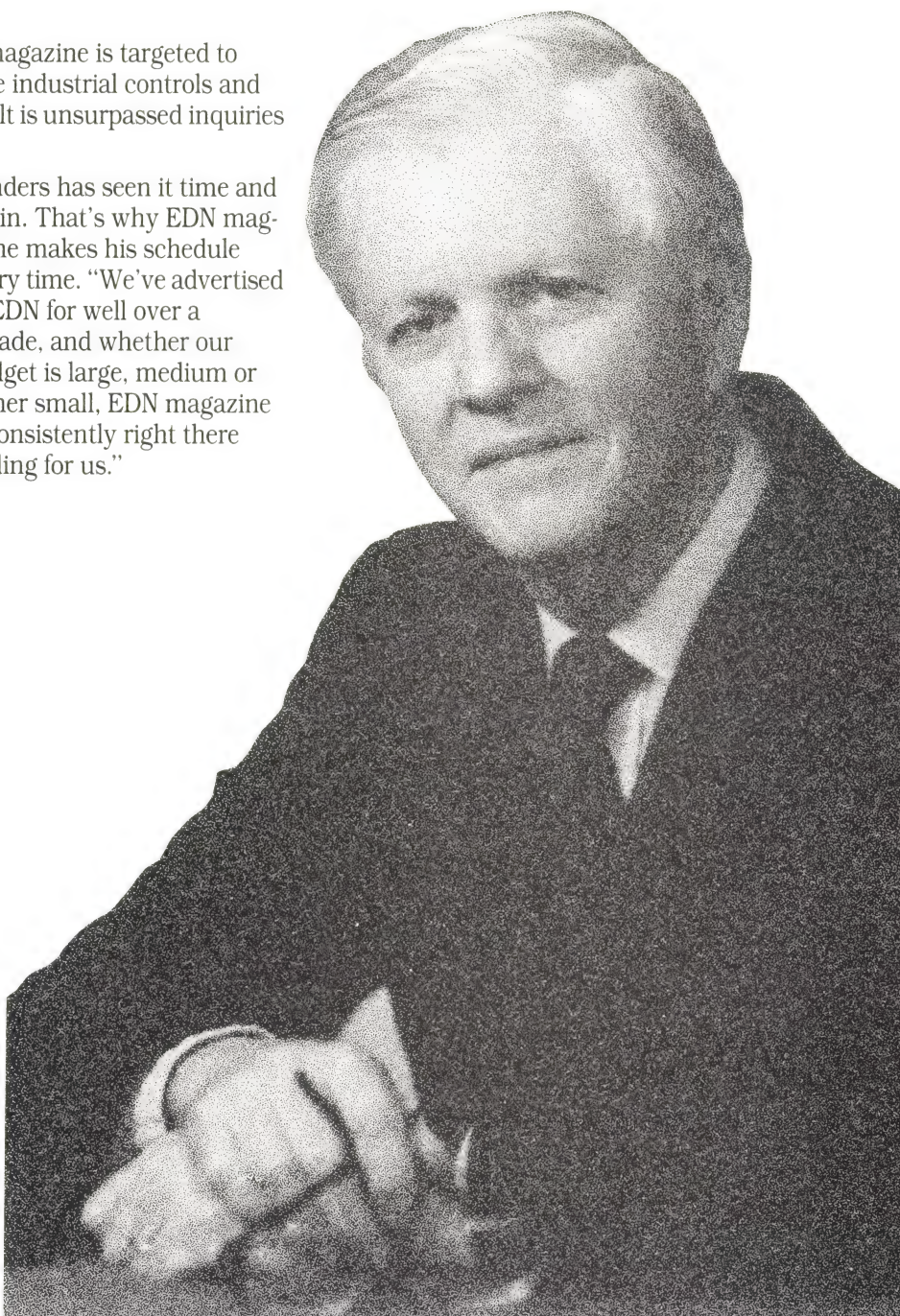
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| 83C751/87C751   | 2K   | 64   | Small package<br>full performance                                                           | 16-bit Autoload & fixed rate<br>(2 total)      | I <sup>2</sup> C*                       | 2 8-bit<br>1 3-bit | 24 SDIP<br>28 PLCC |
| 83C652/87C652   | 8K   | 256  | Pin for pin 80C51 compatible                                                                | 2 Std.                                         | Full duplex UART<br>& I <sup>2</sup> C* | 4 8-bit            | 40 DIP<br>44 LCC** |
| 83C552/87C552   | 8K   | 256  | 10 bit A/D conv;<br>8 high speed outputs;<br>3 Compare/4 Capture registers<br>2 PWM outputs | 2 Std.; Capture/Compare;<br>Watchdog (4 total) | Full duplex UART<br>& I <sup>2</sup> C* | 6 8-bit            | 68 LCC**           |
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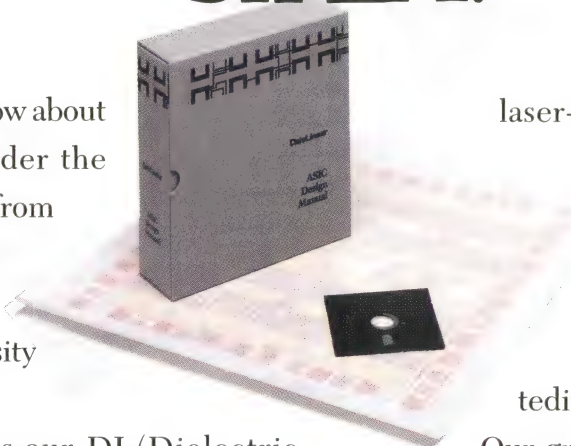
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CIRCLE NO 72



# Feedback plots offer insight into operational amplifiers

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*Many engineers will benefit from a discussion of feedback effects and the construction of feedback plots for operational amplifiers. Part 1 of this series limits its discussion to single-stage amplifiers. Part 2 will conclude with an examination of multistage and composite amplifiers.*

---

Jerald G Graeme, *Burr-Brown Corp*

Feedback plots simplify the analysis of an op amp's closed-loop ac performance by showing bandwidth and stability conditions as a function of the op amp's gain and phase response. These plots also provide insight into noise performance and the special feedback requirements of circuits such as integrating converters and photodiode amplifiers.

Engineers routinely use Bode plots (**Ref 1**) to determine the bandwidth and frequency stability of voltage-gain op-amp circuits. A Bode plot provides a visual representation of an op amp's transfer response and its potential stability. Moreover, such plots define the circuit's pole and zero locations at the intercepts of the response-curve extensions.

The Bode plot of **Fig 1**, for example, shows the interaction of the magnitude response of the open-loop gain ( $|A|$ ) and the reciprocal of the feedback factor ( $1/\beta$ ).

The fraction of the output that feeds back to the input is  $\beta$ . The voltage-divider action of **Fig 1**'s feedback network determines the value of  $\beta$ ; for moderate resistance values,  $\beta = R_1/(R_1 + R_2)$ . For this noninverting example, the feedback equation,  $A_{CL} = A/(1 + A\beta)$ , defines the closed-loop voltage gain.  $A\beta$  is the loop gain, and where it is high:

$$A_{CL} \approx 1/\beta = (R_1 + R_2)/R_1.$$

$A\beta$  represents the amplifier gain available to maintain the ideal closed-loop response. At the point where the loop gain no longer matches the feedback demand, the closed-loop curve deviates from the ideal. The Bode plot graphically defines this limit by plotting the  $1/\beta$  curve with the gain-magnitude response curve of the op amp. Because the  $1/\beta$  line represents the feedback demand, closed-loop requirements will be satisfied as long as this line is below the amplifier-gain curve. Where this condition is no longer true, the actual response drops, following the amplifier's open-loop response downward. The rate of descent for the roll-off is  $-20$  dB/decade (for most op amps) and is characteristic of a single-pole response. In **Fig 1**, the heavier line on the gain-magnitude plot depicts the resulting closed-loop curve.

## Back to basics

For a basic voltage-gain amplifier, the location of the  $f_p$  pole determines the closed-loop bandwidth. In this case, a single-pole roll-off determines the point at



*Bode plots add a visual representation of the op amp's transfer response and provide information on gain, phase, and noise characteristics.*

which the gain magnitude goes below 3 dB (equivalent to 0.707 of its low-frequency level). To find this point relative to the Bode plots, rewrite the closed-loop gain as

$$A_{CL} = (1/\beta)/(1/A\beta + 1).$$

The bandwidth-defining gain error is a result of the  $1/A\beta$  term in the denominator. Because  $\beta$  is constant for the circuit in **Fig 1**, the amplifier gain ( $A$ ) determines the frequency dependence of the loop gain. For a typical op amp, the gain-bandwidth product is constant after the first break frequency occurs and when

$A \approx jf_c/f = j|A|$  and where  $f_c$  is the amplifier's unity-gain crossover frequency. For this common condition,

$$A_{CL} = (1/\beta)/(1 + 1/(j|A|\beta)).$$

The bandwidth is defined in terms of the absolute value (magnitude) of  $A_{CL}$ :

$$|A_{CL}| = (1/\beta)/\sqrt{1 + 1/(|A|^2\beta^2)},$$

which, at the -3-dB point, becomes

$$|A_{CL}| = 0.707(1/\beta) = (1/\beta)/\sqrt{2}$$

Comparing the last two expressions, you can see that the -3-dB bandwidth occurs when  $|A| = 1/\beta$ . This equality is true when the gain supply drops to the exact level of the feedback demand. When you plot these two functions on the same graph, they reach equality at the intersection of the two curves. This intercept pinpoints the closed-loop pole location and defines the circuit bandwidth for the voltage-gain amplifier.

### When it comes to stability

This critical intercept point also exhibits other characteristics that can help you define conditions for frequency stability. By relating the phase shift to the slopes of the gain-magnitude and  $1/\beta$  curves, you can determine the loop phase shift at this intercept. Again, the importance of the intercept is apparent from the closed-loop-gain expression,  $A_{CL} = A/(1 + A\beta)$ . If  $A\beta$  becomes -1, the closed-loop gain will be infinite and will support an output signal even in the absence of an input signal, which is a condition for oscillation. The magnitude of  $A\beta$  is unity only at the intercept point because it is at this point that  $A = 1/\beta$ ; a negative polarity for  $A\beta$  only requires 180° phase shift.

Virtually every practical analog circuit is a minimum-phase system. For such systems, which have only left-half-plane poles and zeros, you can directly read the phase shift from the gain-magnitude response (**Ref 2**). Although many op amps do have a right-plane zero caused by Miller phase compensation, the effects of this zero are suppressed below the unity-gain crossover. For the case of a minimum-phase system, a pole creates a -20-dB/decade response roll-off and a -90° phase shift; a zero produces the same effects but with opposite polarities. Additional poles and zeros simply add to the response slope and phase shift in increments of the same magnitude.

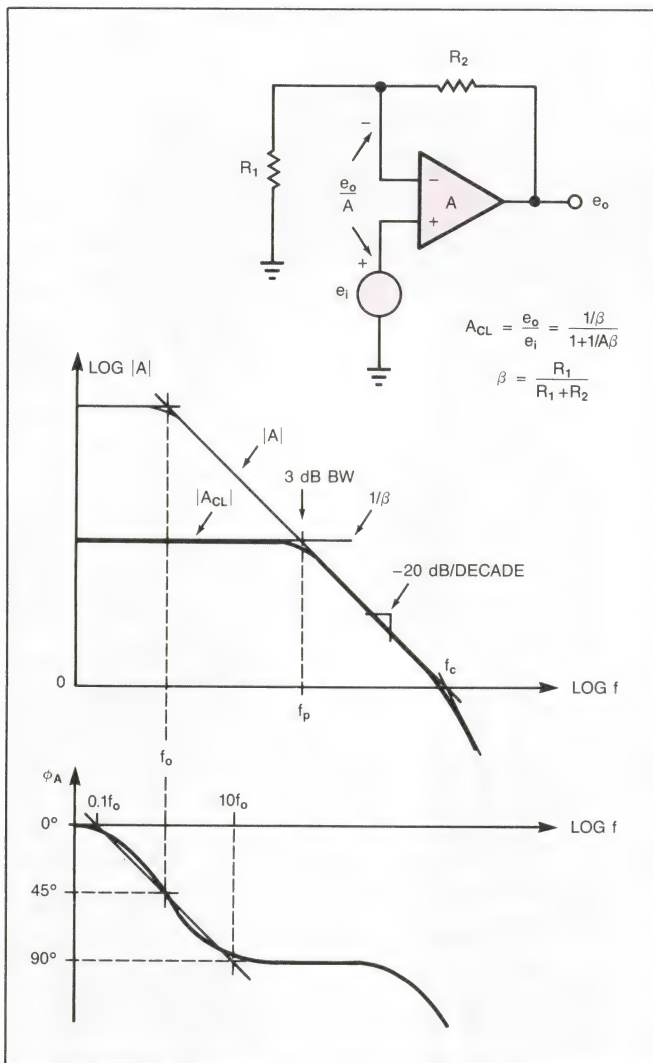


**Fig 1—This feedback analysis provides a summary of loop conditions in the  $1/\beta$  curve and defines the underlying poles, zeros, and phase shift.**



Relying on the feedback phase shift's correlation with the response slope, you can determine its value at the critical intercept from the gain-magnitude and  $1/\beta$  curves. For the example of Fig 1, the gain-magnitude curve has a slope of  $-20$  dB/decade and the  $1/\beta$  curve has a zero slope for a net  $90^\circ$  feedback phase shift at the intercept. This situation leaves a phase margin of  $90^\circ$  out of the  $180^\circ$  that is needed to cause oscillation. Because the intercept is well removed from the open-loop-response break frequencies, the analysis of this example is easier to understand. The intercept occurs after the amplifier's first pole develops the full  $90^\circ$  phase shift, but well before the second pole has any effect.

#### Maximum error is $5.7^\circ$

In cases where the intercept is less than two decades from a response break, the Bode approximation of the phase shift shows a linear slope that has a maximum error of  $5.7^\circ$  (Ref 1). For Fig 1, the phase-shift approximation starts at  $0^\circ$  one decade before the break frequency  $f_0$ . From there, it increases linearly on the log scale to  $45^\circ$  at the break frequency and then to  $90^\circ$  one decade above it.

Using this approximation, you can combine the stability criteria for loop-gain magnitude and feedback phase shift to obtain the rate-of-closure indicator. Rather than computing phase shifts from slopes, you can use this indicator to deal with the slopes directly. Rate-of-closure is simply the difference in slopes of the gain-magnitude curve and the  $1/\beta$  curve when they intercept. This difference reflects the combined phase shift around the feedback loop. For Fig 1, the rate-of-closure is  $20$  dB/decade, which corresponds to a stable  $90^\circ$  phase shift.

In other cases, the slope of the  $1/\beta$  curve is not zero, giving a  $40$ -dB/decade rate-of-closure that indicates an oscillatory  $180^\circ$  of phase shift. Rate-of-closure alone is an exact stability indicator where the intercept is at least two decades away from all other break frequencies. In still other cases, the Bode phase approximation modifies the rate-of-closure result.

#### Feedback network needs its independence

To use feedback relationships to perform circuit analysis, you should consider the feedback network separately. This separation parallels the nature of the op amp's open-loop gain, which is a characteristic of the amplifier in the absence of the feedback network. You only need to retain the loading effects between the amplifier and the feedback network to determine their individual responses (Ref 2). Then, by putting the two responses on the same plot, you can see how they will work together.

Fig 2 shows a generalized feedback condition defined by  $Z_1$  and  $Z_2$ . The equations of Fig 2a directly determine the circuit response for high loop gain and moderate impedances. Nonetheless, the input impedance of the amplifier alters the simplified results of these equations by shunting the feedback network. The inclusion of this loading effect on the feedback network completes the  $1/\beta$  analysis in the circuit of Fig 2b. Here, the op-amp input resistance ( $R_i$ ), differential input capacitance ( $C_{id}$ ), and common-mode input capacitance ( $C_{icm}$ ) all shunt impedance  $Z_1$ . Except for conditions where the feedback impedances have low values, you need to include these amplifier characteristics in your analysis.

Where there is impedance in series with the amplifier's noninverting input, you must add this too—along

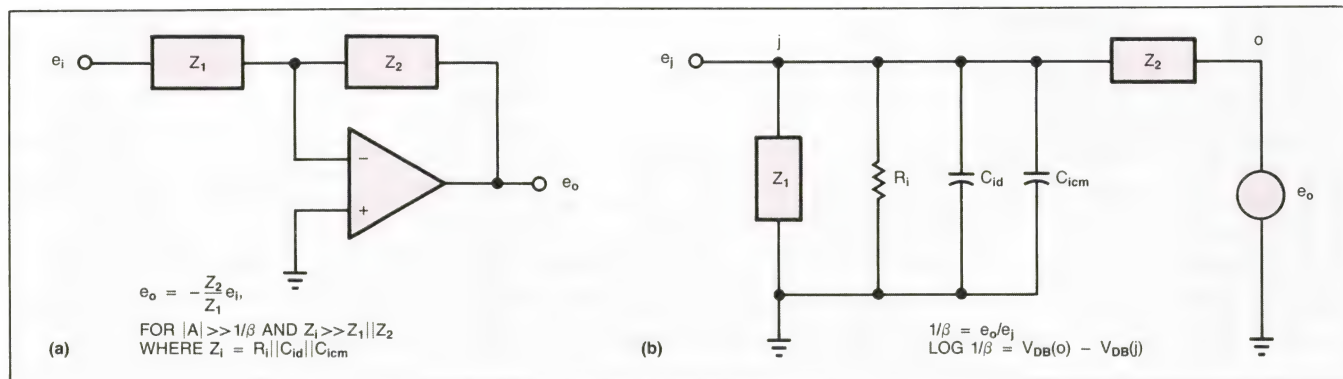


**Fig 2—To determine the  $1/\beta$  curve for the generalized circuit of a, you can draw a voltage-divider circuit that represents the feedback network and the shunting effects of the amplifier input (b).**



*The feedback network's voltage-divider action determines the feedback factor, which interacts with the open-loop gain to generate the overall circuit response.*

with the shunting effect of the input's  $C_{icm}$  capacitance. You can then find the feedback factor from the divider action,  $e_j/e_o$ . For the  $1/\beta$  curve, this result is inverted and, in the logarithmic format of computer simulations, becomes simply  $VDB(o) - VDB(j)$ . By adding this curve to the plot of the amplifier's gain-magnitude response, you can display the characteristics of the critical intercept for subsequent feedback interpretation.

### Gain departures deserve consideration

The  $1/\beta$  curve also communicates performance information across the entire response range of the op amp. For example, it displays loop gain, which provides an indication of gain accuracy vs frequency and the ultimate bandwidth limit. Furthermore, the  $1/\beta$  curve demonstrates that the circuit's signal bandwidth can be different from its noise bandwidth. Note that the previous feedback-network analysis returns  $Z_1$  to

ground as it would in a noninverting op-amp configuration, even though the op amp shown is in the inverting mode.

Underlying the difference between noise and signal bandwidth is the concept of noise gain, which is the source of some of the more common op-amp application problems. For any given feedback network, the inverting and noninverting configurations develop signal gains that differ in magnitude as well as in sign; nevertheless, the feedback conditions remain the same. In both cases, your feedback analysis is concerned with the gain-error voltage developed between the op-amp inputs. This error signal always receives the gain of the noninverting connection, as you would see if you performed superposition analysis. Superposition of the signal between the amplifier inputs grounds the signal source, producing the noninverting configuration.

The same condition holds true for the input voltage noise of an op amp, resulting in the noise-gain characteristic for the  $1/\beta$  curve. In practice, the noise gain and the  $1/\beta$  curve are the same—until they intercept with the gain-magnitude curve. After that, the noise gain rolls off with the amplifier open-loop response but the  $1/\beta$  curve continues on its path. For the noninverting voltage amplifier, the noise gain and the closed-loop gain,  $A_{CL}$ , are the same.

### Watch out for surprises

In inverting configurations, this correspondence does not hold true, giving rise to frequent surprises during attempts at noise filtering. The simplest case of the inverting amplifier, where it is common practice to bypass the feedback resistor, serves to illustrate the inverting relationship (Fig 3). Bypassing the feedback resistor is intended to limit noise bandwidth, and it does indeed remove noise presented as an input signal. However, the circuit will continue to pass amplifier noise across the entire op-amp bandwidth.  $C_f$  shunts the signal supplied through  $R_1$  for the desired lowpass roll-off of the op amp's  $e_o/e_i$  response. To the op-amp noise voltage,  $e_n$ ,  $C_f$  merely presents the unity feedback of a voltage-follower. Noise gain drops to unity but continues out to the open-loop roll-off of the op amp. This leveling off of  $1/\beta$  also shows why the op amp must be unity-gain stable, even though the circuit gain has been rolled off well below the amplifier response. With  $1/\beta$  following the unity gain axis, the critical intercept occurs at  $f_c$ .

While the continued noise gain is at a lower level, it covers much of the amplifier bandwidth, which can

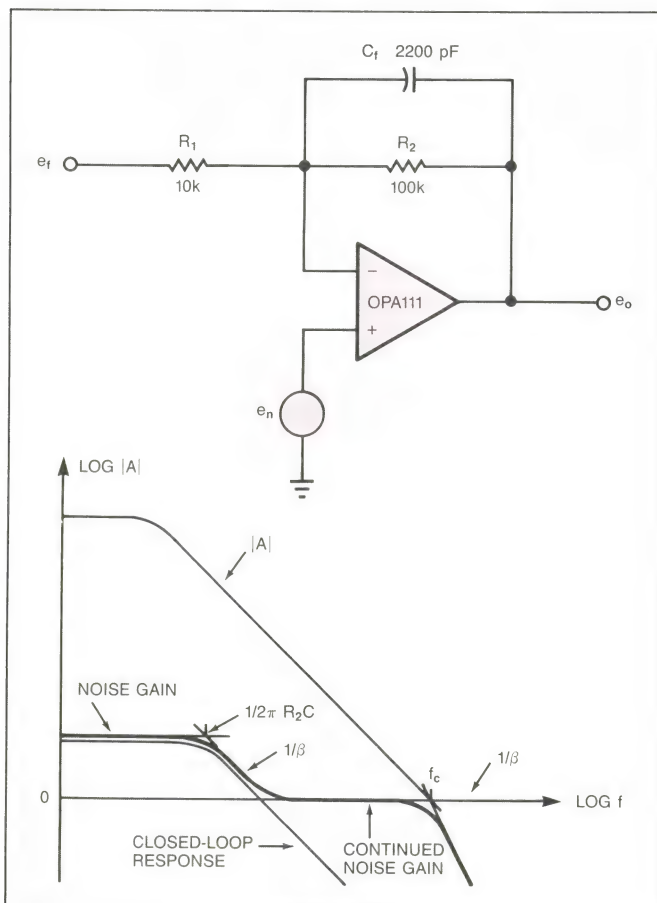


**Fig 3—Highlighting the difference between closed-loop gain and noise gain, this inverting op-amp configuration demonstrates the greater bandwidth that is often available to amplifier noise.**



result in a dramatic increase in output noise. For example, if you're using the 2-MHz Burr-Brown OPA111 shown and choose  $C_f$  to obtain a 2-kHz roll-off, only 0.1% of the amplifier bandwidth will be enclosed in the intended system response. Although the logarithmic scale of the frequency axis may be visually deceptive, the remaining 99.9% of the bandwidth is still available to the amplifier's voltage noise. For an initial gain of 10, the output noise that this amplifier produces is more than doubled by the bandwidth effect. Many active-filter configurations are subject to the same limitation.

The only way to avoid excessive noise bandwidth is to restrict the frequency range of the op amp. By doing so, the control of the noise response switches from the  $1/\beta$  curve to the amplifier roll-off. Where the op amp has provision for external phase compensation, this control is a simple matter and permits you to remove bandwidth from signal and noise alike. However, because most op amps lack an external-phase-compensation facility, passive filtering within the feedback loop offers a broader solution (Ref 3). Such filtering introduces a capacitive shunt to ground following the amplifier but within the feedback loop.

You can also demonstrate the extended noise bandwidth of an integrating converter using a feedback plot but, more importantly, the curves illustrate the dynamic-range limit for integrator-based instrumentation. In Fig 4, the integrator  $1/\beta$  curve also levels off at the unity-gain line for continued noise gain out to where the op amp rolls off. Be aware that this action has far less noise significance for the integrator because of its increasing gain at lower frequencies. Integrators designed for operation to 1 kHz or even higher are generally unaffected by the added noise bandwidth.

Nevertheless, the feedback plot for the integrator demonstrates a unique bandwidth limitation involving two critical intercepts. Not only does the  $1/\beta$  curve intercept the gain-magnitude curve at the high-frequency extreme, but it does so at the low-frequency end as well. Each intercept indicates a lack of amplifier gain for support of the feedback and a departure from the ideal response. At the high end, the  $1/\beta$  curve and noise-gain level off, leaving  $A_{CL}$  to continue as long as the loop gain lasts. Next,  $1/\beta$  intercepts the gain-magnitude curve at  $f_c$  where the noise gain rolls off.

This intercept is a high-frequency 3-dB point for the integrator response, which then usually rolls up rather than down. Upward response in this region is due to signal feedthrough caused by the feedback elements

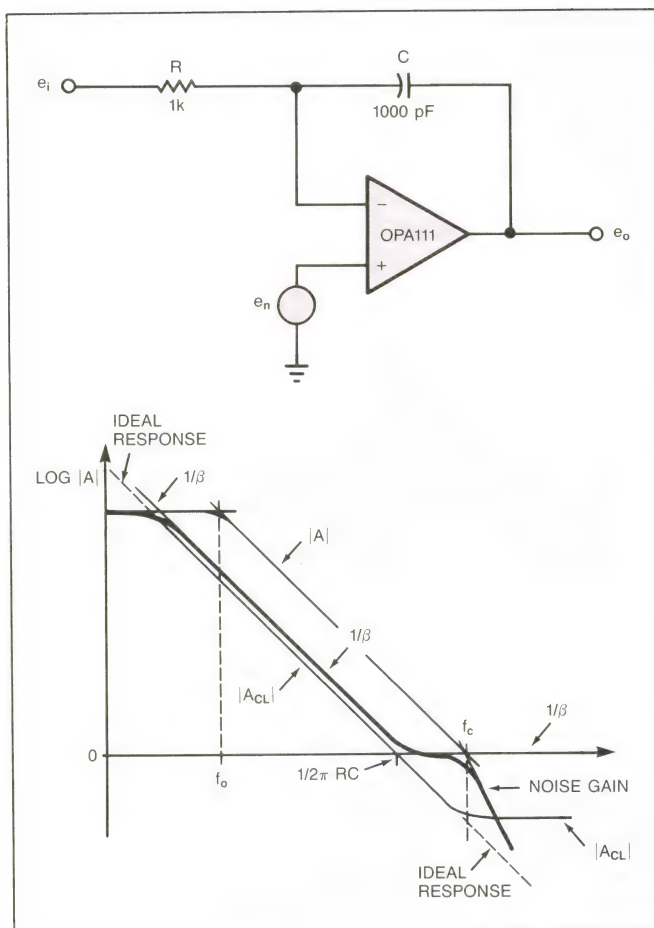


**Fig 4—Defining the dynamic range for integrating data converters,** the integrator  $1/\beta$  curve displays upper and lower intercepts with the gain-magnitude response.

in the absence of loop control. At the lower frequencies, the increasing gain demand encounters the dc gain limit of the op amp. This intercept marks the second 3-dB point for the integrator response, which sets the range for accurate performance. Both intercepts have a 20-dB/decade rate-of-closure, indicating stable operation.

### Consider the gain error

Between the two integrator-response limits is the usable dynamic range for dual-slope A/D and V/F converters. The gain error limits this dynamic range; the plots are a graphic representation of this error. The gain error is inversely related either to a circuit's loop gain or the difference between the amplifier's open-loop gain and the feedback demand of  $1/\beta$ . On the response plots, the gain error is the vertical distance between the two curves. For the Fig 4 integrator, this separation decreases following  $1/\beta$ 's encounter with the unity-gain axis. From there, the separation finally reduces to zero at  $f_c$ . The gain error then becomes the distance between the dashed continuation of the ideal integrator response and the actual  $A_{CL}$  response. Graphically, this distance is the source of the large-signal limitation for integrating converters where higher signals correspond to the upper frequencies.

At the other end of the converter range, lower-level



*For minimum-phase systems, you can directly read phase-shift information from the Bode plot of the op amp's gain-magnitude response.*

signals demand low-frequency integrator operation that encounters a similar limitation. Below the frequency of the op amp's first pole,  $f_o$ , the separation between the  $1/\beta$  and gain-magnitude curves again drops, signaling reduced loop gain. Moving further down in frequency, the  $1/\beta$  curve finally crosses the op amp's dc-gain level, and the actual response flattens again. For integrating-type converters, this action defines a range of performance that is accurate to within 3 dB from  $f_c$  down to the lower intercept. To extend the dynamic range, you move the lower intercept downward either with a lower integrator-time-constant or with boosted dc gain.

A higher accuracy dynamic range results from the unique loop-gain conditions of the integrator. The loop gain is constant for the integrator from  $f_o$  to its unity-gain crossing. The gain error in this range is constant as marked by the uniform separation of the gain-magnitude and  $1/\beta$  curves. You can compensate for such an error by making a fixed adjustment to the

feedback network, leaving gain-accuracy bounded by the stability of the network. This limit permits you to adjust the more restricted dynamic range to 0.01% levels. For the OPA111 op amp and a 100-kHz integrator crossover frequency, this more precise dynamic range has a span of 100,000:1.

### Feedback factor may introduce surprises

The previous discussion of the inverter and the integrator considered the feedback network independent of the amplifier input shunting. Although engineers frequently use this simplification, they often encounter unexpected results. Because of the feedback factor, most first-time users of op amps with large feedback-resistance values are surprised by the response curve. Transient-response ringing or even oscillation sometimes occurs; the common cure is a capacitive bypass of the feedback resistor. The  $1/\beta$  curve can display the problem and provide some guidance in the selection of the bypass capacitor.

Underlying the problem is the op-amp input capacitance's effect on the feedback factor. By including this capacitance with the voltage divider formed by the feedback resistors, you can achieve the results of the  $1/\beta$  curve in Fig 5. This curve rises at high frequencies, increasing the rate-of-closure and flagging the need for closer stability analysis. The phase margin drops as  $1/\beta$  rises and, at the limit, goes to zero if the  $1/\beta$  rise spans two decades of frequency. Generally, the span is much smaller than that and the Bode phase approximation evaluates the actual conditions. The key to minimizing the effect on the feedback factor is the low input capacitance that the small input FETs of the OPA128 device provide. The net 3 pF of input capacitance leaves the response undisturbed until the parallel combination of the two resistors reaches 50 k $\Omega$ .

The capacitive bypassing of  $R_2$  increases the high-frequency feedback, which counteracts the shunting of  $C_{ia}$  by leveling off the  $1/\beta$  curve. The selection of this capacitor is better illustrated by Fig 6's photodiode amplifier. You can reduce the nonobvious bandwidth of this application to an equation. The circuit contends with diode capacitances at the input that can reach 20,000 pF. As a result, the break in the  $1/\beta$  curve is generally far removed from the intercept, making the rate-of-closure analysis accurate without requiring any adjustment of the phase-shift approximation.

Unfortunately, the bandwidth for the circuit of Fig 6 is obscured by its function. Because its function is a current-to-voltage conversion, rather than simple volt-

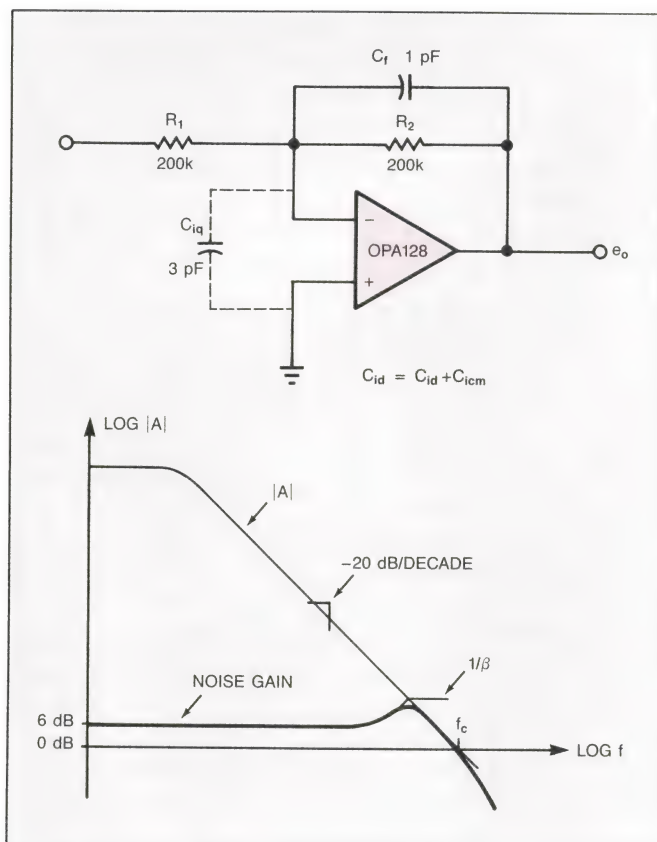


**Fig 5—Higher feedback resistances will react with the op amp's input capacitance to produce a peaking effect, which the  $1/\beta$  curve anticipates.**



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age gain, you cannot draw the signal-gain curve on the gain-magnitude response to estimate bandwidth. When you inspect the circuit to ascertain its bandwidth limitation, you'll see that the only inherent break frequency is that of the feedback resistance and the capacitance of the input circuit. By plotting the  $1/\beta$  curve, however, you can see that the loop gain remains to support the ideal feedback condition far beyond the  $f_i$  break frequency.

Initially, the  $1/\beta$  curve is flat at unity because of the direct output-to-input connection of  $R_f$ . When the feedback is later shunted by  $C_D$  and  $C_{ia}$ ,  $1/\beta$  rises at a 20-dB/decade rate. The transition between these regions occurs at

$$f_i = 1/2\pi R_f(C_D + C_{ia}),$$

where  $C_{ia} = C_{id} + C_{icm}$ .

The intercept with the gain-magnitude curve marks the end of the response rise for the noise gain. This curve has a  $-20$ -dB/decade slope so, if left uncompensated, the rate-of-closure at the intercept will be  $40$  dB/decade. Thus, the plot indicates two poles at that intercept frequency,  $f_p$ . This intercept is the point at which there is no longer sufficient amplifier gain for the feedback-factor demand, and it indicates response roll-off independent of the op-amp function. Any amplifier function would then roll off with a slope equal to the rate-of-closure.

### Stability depends on phase compensation

Because the rate-of-closure is  $40$  dB/decade, you should examine phase shift at the intercept to determine the phase compensation necessary for stability. When the various break frequencies are well removed from the intercept, the rate-of-closure accurately reflects  $180^\circ$  of phase shift for the uncompensated loop. To avoid oscillation and to achieve good damping characteristics, you must reduce this phase shift by at least  $45^\circ$  through roll-off of the  $1/\beta$  curve.

According to the Bode phase approximation, this phase shift is the amount of phase introduced at a break frequency. Choosing  $C_f$  to break with  $R_f$  at the intercept frequency,  $f_p$ , yields  $45^\circ$  of phase margin. Accompanying this phase condition is a 3-dB peak in the signal response, which for a 2-pole response pushes the  $-3$ -dB bandwidth out to  $1.4f_p$ . For the OPA111 and the feedback elements shown, the 3-dB response extends to  $48$  kHz. (You can extend this analysis to lower capacitance levels, and the common solution

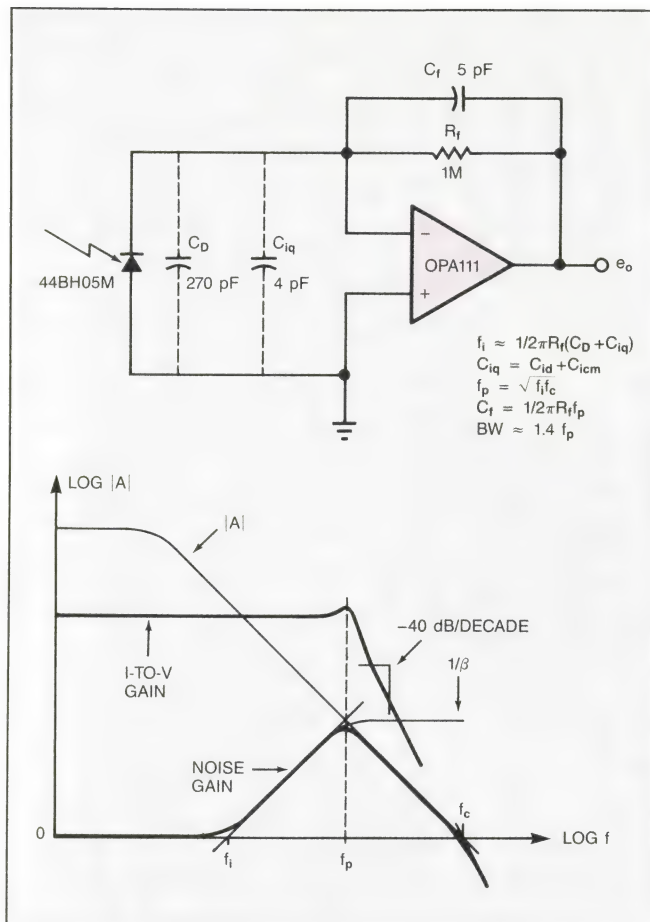


**Fig 6—A photodiode amplifier's current-to-voltage function serves to obscure its bandwidth and stability, but you can rely on feedback-loop conditions to define its performance.**

mentioned above will still suffice—even for the high-feedback-resistance case of Fig 5.)

As long as  $C_f$  breaks with  $R_f$  at the frequency of the intercept, the  $1/\beta$  rise contributes no more than  $45^\circ$  of phase shift. In the range where the op-amp phase shift is  $90^\circ$ , this rise leaves a stable  $45^\circ$  phase margin. Nevertheless, as the op amp approaches its crossover frequency,  $f_c$ , its contribution to phase shift moves toward  $135^\circ$ . The rule of thumb for selecting  $C_f$  remains valid, however, because any intercept near  $f_c$  must be a result of a  $1/\beta$  rise of short duration. The added phase shift of the amplifier, accompanied by a necessary decrease in feedback phase shift at the intercept, results in a net zero effect. By simple sketching of the phase approximations for the  $1/\beta$  and gain-magnitude curves, you can show this transition.

### Simple, yet elegant

To select the compensation capacitance, it is desirable to reduce the graphical analysis to an equation. Luckily, the response plots provide an elegantly simple solution. Straight-line extensions of the  $1/\beta$  and gain-magnitude curves form a triangle with the horizontal axis. These extensions have equal but opposite slopes, which form an isosceles triangle. The peak of the triangle, located over the center of its base, lies at the average of the base end points. Mathematically, this



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average point is equal to

$$\text{Log } f_p = (\text{Log } f_i + \text{Log } f_c)/2.$$

Given the expressed logarithmic nature of the frequency axis, you can reduce this relationship to the simple geometric mean of the two characteristic frequencies:

$$f_p = \sqrt{f_i \times f_c},$$

where  $f_i = 1/2\pi R_f(C_D + C_{id} + C_{icm})$ , and  $f_c$  equals the unity-gain bandwidth of the op amp.

For a third input-circuit effect, the  $1/\beta$  curve demonstrates stable conditions where typical gain and phase plots would point to oscillation. In addition to input capacitance, op amps have input inductance; this combination produces a high-frequency resonance. The inductance is small but inescapable, being associated with internal input wires and being compounded by external wiring.

### When it comes to high frequency . . .

For very high-frequency amplifiers, like the OPA620 video amplifier of **Fig 7**, sufficient amplifier gain exists at the resonant frequency to give the appearance of zero gain margin. A comparison of the output signal ( $e_o$ ) with that at the summing junction ( $e_j$ ) produces the plot's gain and phase responses. Following unity crossover, the gain curve rises again above the unity axis; this rise generally guarantees oscillation for lower gain levels. Adding to stability concerns is the phase plot, which swings wildly through  $180^\circ$  during the gain peak.

By adding the  $1/\beta$  curve to the plot, you can see that this curve does not intersect the gain peak but merely rides over it. Without an intercept there is no oscillation, regardless of the phase shift, because the loop gain is insufficient. Loop-gain demand rises in synchronization with the gain peak because the resonant circuit also alters the feedback network.

In many cases, the gain peaking results from conditions in the amplifier output rather than from the input circuit. In such a case, no corresponding modification of feedback occurs, and an intercept and oscillation result. However, for **Fig 7**, the gain margin remains high, as you can see by the separation between the  $1/\beta$  curve and the gain response when the phase reaches  $180^\circ$ . This separation remains large throughout the region of higher phase shift, indicating good relative stability.

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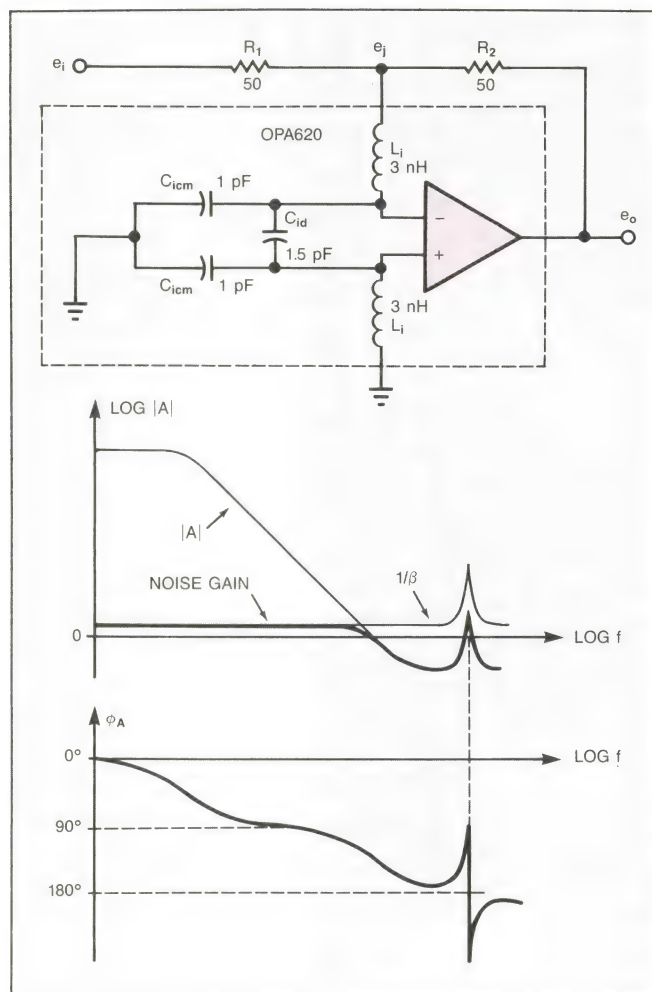


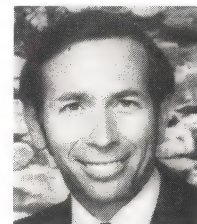
**Fig 7—Although amplifier gain and phase plots suggest instability, the  $1/\beta$  curve shows stable conditions for a circuit with input-lead inductance.**

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### Author's biography

Jerald G Graeme is manager of instrumentation-components design at Burr-Brown Corp (Tucson, AZ), and directs a linear-IC development group. He holds a BSEE from the University of Arizona and an MSEE from Stanford University. Jerry has eight patents to his credit. His leisure pursuits include photography, woodworking, and scuba diving.



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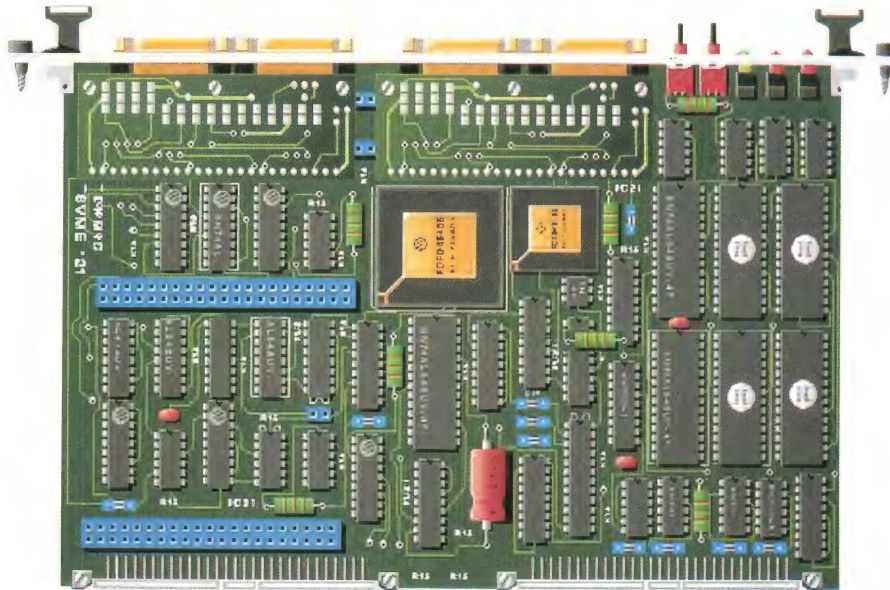
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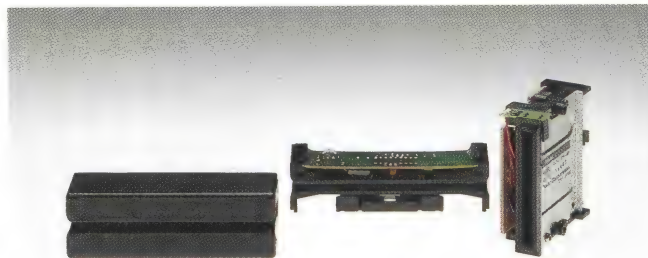
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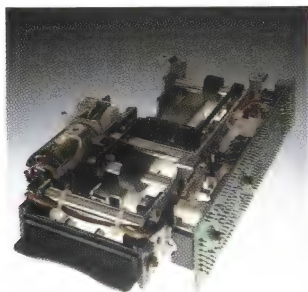
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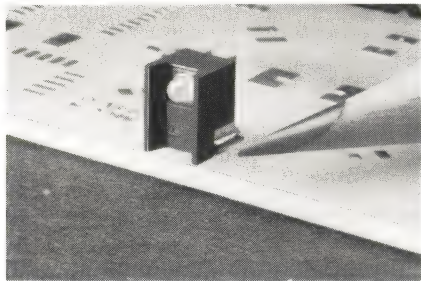
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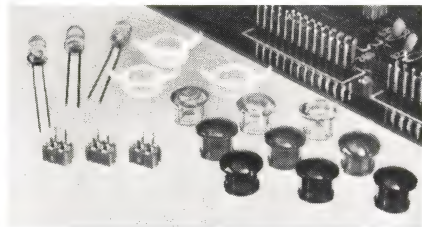
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# FFT analyzers make spectrum analysis a snap

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*Although swept-spectrum analyzers and FFT analyzers arrive at essentially the same result, their methods differ. The FFT analyzer and its method offer some distinct advantages. If you understand the limitations and potential error sources of FFT-based analysis, you'll be sure to use the right analyzer for your measurements.*

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George Dovel, Hewlett-Packard Co

A common source for FFT analysis is the dedicated FFT analyzer (**Fig 1**), more familiarly known as an "FFT spectrum analyzer" or a "dynamic signal analyzer." Other product types—for example, digital oscilloscopes linked to FFT software or PC plug-ins—can also provide FFT results. Different types of products provide varying degrees of performance in obtaining their FFT results, however. To understand why, you need to understand the FFT process.

As you may recall from Fourier series theory, you can represent any signal as a combination of sine and cosine waves at different frequencies and amplitudes. That's the cornerstone of the fast Fourier transform. To understand the advantages of FFT analysis, consider briefly how FFT analyzers work. By digitizing

incoming analog signals and mathematically converting this "time record" to a frequency spectrum, an FFT analyzer provides low-frequency spectrum and network analysis. The conversion process simulates the action of hundreds of parallel filters, each measuring the signal level at a particular frequency.

The first major advantage of FFT analysis is its ability to measure transient signals. A swept-spectrum analyzer effectively sweeps a filter across the spectrum, measuring one frequency at a time. Unfortunately, sweeping the input waveform is a technique that works well for stable signals, but gives misleading results for signals that change during the sweep time.

## Take a picture

The simulated parallel filtering of the FFT analyzer overcomes this difficulty by taking a "snapshot" of the signal, then processing all the frequencies simultaneously. The analyzer's ability to track a fast-changing signal, however, depends on the instrument's computing capability.

Parallel processing yields another potential advantage—faster measurements. The swept-spectrum analyzer or swept-spectrum network analyzer must sweep frequencies from point to point, stopping to let its filter settle at each point; by contrast, the FFT analyzer measures across the frequency span in one shot. At lower frequency spans, the FFT analyzer can provide faster measurements. **Fig 2** is a spectrum measurement, taken at 100-Hz resolution, that compares the



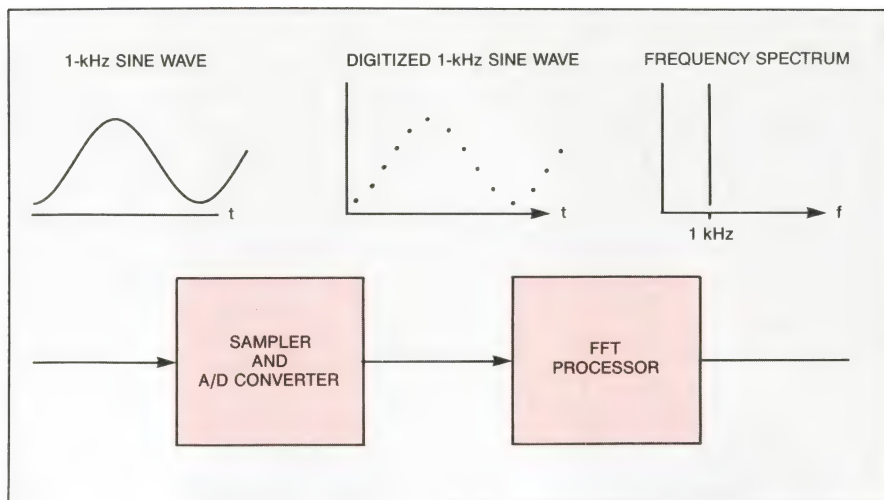


**Fig 1**—A simple FFT analyzer digitizes a time-domain signal and then converts it to the frequency domain.

time required by a swept-spectrum analyzer (**Fig 2a**) with that required by an FFT analyzer (**Fig 2b**). The measurement times can vary widely, but in this particular case, the FFT analyzer was about 100 times faster.

In a swept-spectrum analyzer, the bandwidth of the sweeping filter limits the frequency resolution. The FFT analyzer doesn't have this limitation. Some FFT analyzers can resolve signals that are spaced less than 100  $\mu$ Hz apart. In FFT analyzers, in most cases, the resolution is limited only by the amount of time you're willing to devote to the measurement. Increasing the resolution of the FFT analyzer increases the time it takes to measure the signal.

Their independence from analog filtering gives FFT analyzers another key advantage: They can offer both spectrum and network modes in one instrument, without compromising either mode. Because a math algorithm performs spectrum and network analysis in an FFT analyzer, the measurement mode doesn't depend on any specific analog hardware.

### View time and frequency domains

The use of digital processing also yields another benefit: The analyzer can provide results in both the time domain and the frequency domain. Having both representations increases the analyzer's value to you

and improves the quality of your measurements. In many cases, you can understand a signal or device better by viewing it from both perspectives. Many FFT analyzers also offer the amplitude domain, which provides statistical measurements such as the histogram.

The FFT analyzer clearly provides important benefits, but it does have some drawbacks. The first is the frequency range: Most FFT analyzers have upper frequency limits between 40 and 100 kHz.

Another limitation for some applications is the dynamic range, the ability to measure low- and high-level signals simultaneously. Most FFT analyzers offer between 70 and 80 dB of dynamic range. Several manufacturers, however, have added a stepped-sine measurement mode to their analyzers, improving the analyzers' dynamic range to well over 100 dB.

### When dynamic range isn't enough

If an FFT analyzer's frequency coverage and dynamic range aren't sufficient for your measurements, the swept-spectrum analyzer is clearly the instrument you should choose. On the other hand, for transient signals, faster measurements, and better frequency resolution, the FFT analyzer is a better choice.

With its combined spectrum- and network-analysis capabilities, the FFT analyzer is finding many applica-

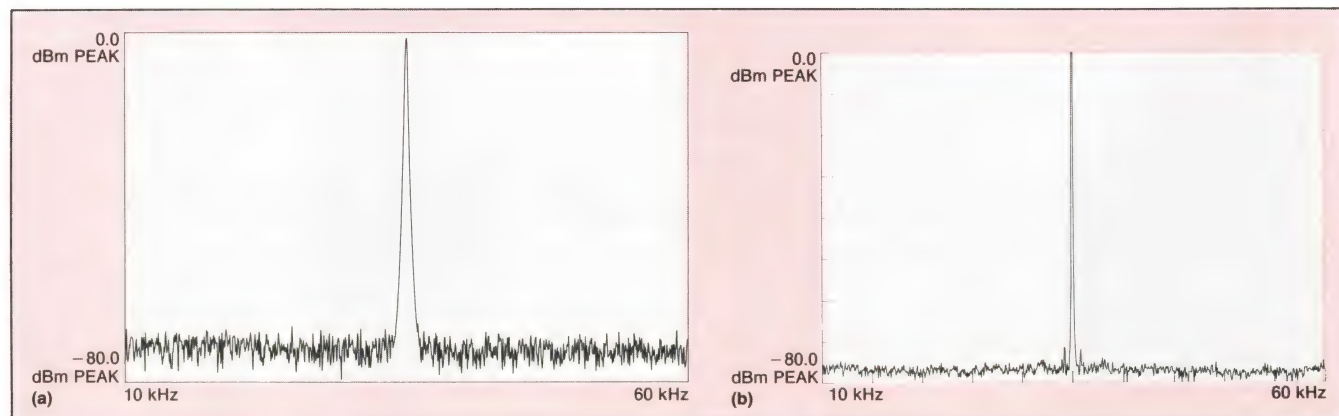
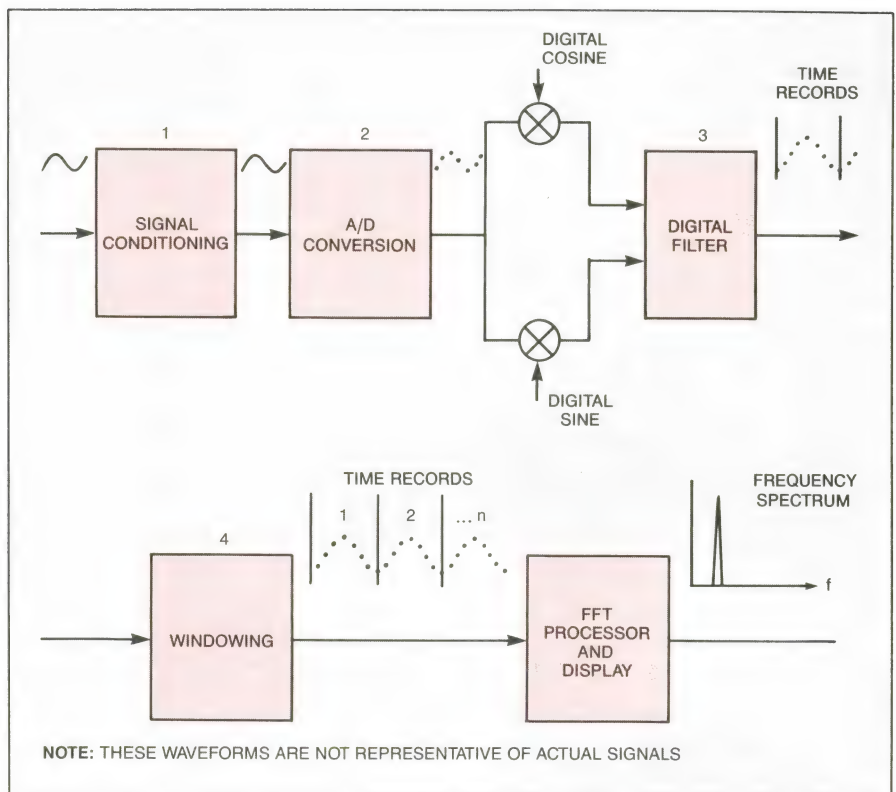


**Fig 2**—Although the results of measuring a signal with a swept analyzer (a) and an FFT analyzer (b) are practically the same, the FFT analyzer is significantly faster.



**Fig 3—Before the frequency-domain output is ready for the FFT analyzer's display, the analyzer processes the signal with signal-conditioning circuits, an ADC, digital filters, windowing functions, and the FFT processor.**



tions in the design and testing of electronic products and systems. Engineers currently use FFT analysis to test telecommunications and data-communications equipment, consumer audio products, instrumentation, industrial electronics, electrical equipment, and electronic components.

Some spectrum-analysis examples include phase-noise measurements, harmonic distortion, modulation analysis, and signal-stability checks. For these measurements, the extremely narrow frequency resolution of FFT analysis can be quite helpful. In electronic-network analysis, for example, the FFT analyzer provides fast measurements on filters, amplifiers, and communication lines. A manufacturer of personal paging devices, for example, can quickly test the response of the voice filter and adjust or discard units that don't meet specifications.

Measuring loop behavior in feedback-control systems is another area in which FFT analyzers are currently solving design and test problems. These systems can be purely electrical (for example, switching power supplies) or electromechanical (for example, disk drives and robotics). The control-system designer frequently needs to measure response in both the frequency domain (transfer function) and the time domain (impulse response), so the multifunction FFT analyzer is a good choice.

### The FFT algorithm makes assumptions

The FFT algorithm makes several assumptions about the signal it's processing. The algorithm doesn't check to verify the validity of these assumptions for a given input, and it will produce invalid results unless you validate the assumptions. If you have a basic un-

derstanding of what it takes to provide good answers, you'll be more successful in choosing and applying an FFT analyzer.

**Fig 3** is a block diagram of an FFT analyzer. Different manufacturers use slightly different designs; **Fig 3** shows a generalized diagram of the technique that Hewlett-Packard uses in its analyzers. There are five general steps in performing FFT analysis: signal conditioning, A/D conversion, digital filtering, data windowing, and finally, the FFT itself.

In conditioning the input signal, the analyzer's front ends perform several important functions as soon as the signal enters through the front panel. The first is ac or dc coupling. This option is important if you need to remove unwanted dc biases in the measurement setup. The second action is amplifying or attenuating the input signal to provide optimum levels for the A/D converter. These input amplifiers are differential in some FFT analyzers; other analyzers offer you the choice of either floating or grounding the inputs.

### Exorcise ghosts from the signal

The third function of the signal-conditioning circuitry is antialias filtering, which represents one of the key differences between dedicated FFT analyzers and most products that provide FFT analysis as a secondary feature. An analyzer that doesn't have adequate protection from aliasing can display frequency components that don't exist in the incoming signal. Aliasing is a potential problem in all sampled systems, not just FFT analyzers. It can occur (according to the Nyquist criterion) if the sampling frequency is less than twice as high as the highest frequency component in the incoming signal. Given at least two samples per cycle, the



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## *By digitizing incoming analog signals, an FFT analyzer provides low-frequency spectrum and network analysis.*

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FFT analyzer can correctly estimate the frequency of a sine wave. If you don't have at least two samples per cycle (that is, if you're not sampling at least twice as fast as the incoming signal), the FFT could incorrectly estimate the signal's frequency.

Fig 4 provides an example of aliasing. Assume you've set the analyzer to measure frequencies from 0 to 10 kHz, disabled the antialiasing filter, and applied a 50-kHz sine-wave input trace. Because the measurement is only looking for sub-10-kHz components of the 50-kHz sine wave, no signal should appear in the measurement, but aliasing causes a false frequency component just above 1 kHz. (The effect of aliasing is to "fold" a higher frequency component down in frequency.)

The solution to the aliasing problem seems simple enough. First, the analyzer manufacturer selects the maximum frequency ( $f_{\max}$ ) that its analyzer will measure, then it makes sure the sampling frequency is at least twice that frequency. This step ensures that the analyzer can accurately measure the frequencies of interest. Next, the manufacturer inserts a lowpass, antialiasing filter to remove all components above  $f_{\max}$ , thus ensuring that the measurement will exclude all frequencies except those you're interested in.

### **Filter has a transition band**

Two factors complicate this simple solution. First, and easiest to address, is the fact that the antialiasing filter has a transition band between the passband and the stopband. The analyzer may fold signals falling in the transition band down into the measurement results, because they're not completely attenuated by the filter. The best way around this problem is to push the sampling frequency slightly above two times  $f_{\max}$ , so that it is twice the frequency at which the stopband actually starts, not twice the frequency you're trying to measure. Although this solution may seem fairly obvious, many vendors don't push the sampling frequency above two times  $f_{\max}$ .

The second complicating factor in alias protection—the FFT analyzer's resolution—is much harder to address. The resolution advantage of FFT analyzers comes from their ability to measure at very narrow spans—a typical FFT analyzer might have a maximum span of 100 kHz and a minimum span of 100 mHz. However, an antialiasing filter designed for the 100-kHz span won't be much help on the 100-mHz span.

One possible solution would be an antialiasing filter for every span in the analyzer, or a filter with se-

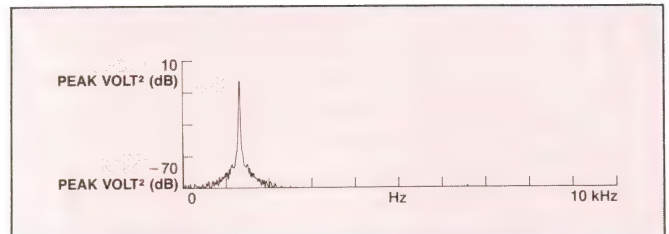


**Fig 4—Even though the input waveform is a 50-kHz sine wave, aliasing causes a nonexistent frequency component to appear in the output trace just above 1 kHz.**

lectable cutoff frequencies. Unfortunately, cost, size, performance, and instability make implementing such a scheme difficult.

Most dedicated FFT analyzers have another approach to solving the aliasing problem. They use a combination of analog and digital filtering. For example, HP analyzers have a fixed sampling frequency and employ one antialiasing filter. This scheme solves the aliasing problem. Next, a digital mixer heterodynes the center frequency to the value selected by the user. Then a digital decimating filter sets up the frequency span. This scheme solves the resolution problem.

Fortunately, most manufacturers of dedicated FFT analyzers have solved the aliasing problem, so you don't have to worry about it. Alternatives to the dedicated FFT analyzer, however, may not always offer optimum alias protection. In any case, always check the data sheet to make sure that whatever product you're considering does indeed have complete protection from aliasing.

### **Most FFT analyzers use standard ADC techniques**

The A/D-conversion step is straightforward enough. Most FFT analyzers employ standard A/D-converter techniques to provide a digital representation of the analog input signal. The confusing part is understanding the manufacturers' specs, because there's no standard way of specifying A/D conversion in FFT analyzers. Some vendors specify bits of resolution; others specify dynamic range. Very few provide all the data you need to fully understand what's happening to your signal. For example, two analyzers on the market offer about the same dynamic range (72 vs 70 dB) under many measurement setups. One of the analyzers has 16-bit A/D converters; the other has 13-bit A/D converters.

Specifying an A/D converter's performance in bits of resolution tells only part of the story. The spec is useful only if the analyzer can use all of the converter's



bits productively. More useful than bits of resolution is the dynamic-range spec. As mentioned, dynamic range indicates the difference between the largest and smallest signals that an analyzer can measure simultaneously. An analyzer with an 80-dB dynamic range, for example, can measure a 0-dBV signal and a -80-dBV signal simultaneously.

Several factors limit the actual dynamic range you obtain with a given measurement. The biggest threat to your dynamic range is an improper range setting, one that's either not high enough (causing overloads) or not low enough (causing poor amplitude resolution and a low S/N ratio). Although it's the biggest threat, it's also the one you have the most control over.

A group of factors inherent to the analyzer may give you less of a dynamic range than the vendor specifies. You're usually safe at the higher A/D-converter voltage-range settings—the following problems are more noticeable at lower voltage ranges with wider frequency spans. Any of these factors could be a problem; manufacturers should specify the problem parameters.

The first problem parameters are harmonic and intermodulation distortion, which are generated by nonlinearities in the analyzer's input circuitry. Another factor is alias responses—higher frequency components that the alias-protection filter may not fully attenuate. And then, under certain operating conditions, the analyzer may generate spurious responses. Triggering, for example, can be a source of spurs in the input channel. Finally, the fundamental noise floor in the input circuit will ultimately limit the dynamic range the analyzer can achieve.

You can use either of two digital-filtering techniques to provide different frequency spans. You can change the sampling rate, or you can keep the sampling rate fixed and use a digital local oscillator and a decimating filter to provide the desired center frequency and span. As mentioned, the latter method has some distinct advantages.

Another important advantage is zooming, which is the ability to focus the measurement span anywhere in the analyzer's frequency range. Without zooming, the measurement span always starts at 0 Hz. For example, you may have a span selection as narrow as 100 mHz, but it can only be applied to the 0- to 100-mHz span, because it must start at 0 Hz.

Assume, for example, that you have an analyzer with a maximum span of 100 kHz and a minimum span of 100 mHz. With zooming, you can center that 100-mHz span anywhere in the overall 100-kHz range. If

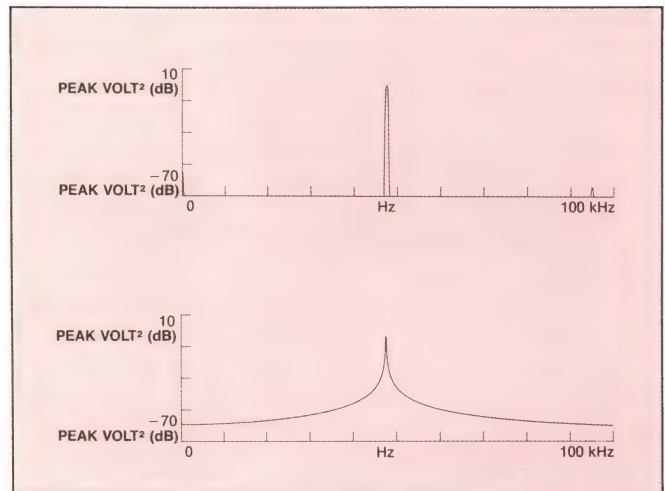


**Fig 5—Trying to measure a signal that isn't periodic from time record to time record causes the energy from a single frequency to spread across a range of frequencies.**

you have a 99-kHz signal with sidebands just 500  $\mu$ Hz away, you can zoom in with the 100-mHz span and see the sidebands with no trouble. This procedure would be impossible without the zooming capability.

You can zoom in two different ways. Although you can zoom with a software algorithm, zooming with a hardware filter provides the same level of resolution at a much higher speed than software zooming provides. When you use either scheme, you obtain a time record that's a filtered block of data samples. The next step is to prepare that block for FFT processing.

The FFT assumes that the signal it's processing is periodic from time record to time record. If the signal is not periodic in the time record, the FFT won't estimate the frequency components accurately. The result is called leakage, and it has the effect of spreading the energy from a single frequency across a range of frequencies. **Fig 5** shows the effect of leakage on a spectrum measurement.

### Leakage spreads the spectrum

Data windowing is the solution to the leakage problem. Multiplying the time record by a weighting function, or a window, forces the signal to be periodic in the time record. It distorts the data in the time domain to improve accuracy in the frequency domain. (To measure in the time domain with no distortion, you can choose not to apply a window.)

A variety of windows are available in most analyzers. Some of the more common window types are the Hanning, flat top, force, and exponential windows, and the



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*The first major advantage of FFT analysis is its ability to measure transient signals.*

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uniform or rectangular window (which has the same effect as that of not applying a window). The choice of a window depends on the type of signal you're measuring and what you most want to learn from the measurement. For example, the Hanning window offers good frequency resolution at the expense of some amplitude accuracy. The flat top, on the other hand, provides better amplitude accuracy with a tradeoff in frequency resolution.

In most FFT analyzers, the FFT algorithm itself is embedded in the hardware or software of the analyzer, so all you need to concern yourself with are the resolution and the speed of the FFT algorithm. The resolution of FFT analyzers is usually given in lines. One line is a discrete frequency output from the FFT algorithm. The most common offerings have 400 and 800 lines, though some analyzers have as few as 25 lines, and you can find analyzers with 3200 lines or more.

#### How variables relate

An FFT analyzer's time-record length, frequency span, frequency resolution, and number of FFT lines are interrelated:

- Frequency span = (frequency resolution)  $\times$  (number of FFT lines)
- Frequency resolution =  $1/\text{time-record length}$
- Time-record length = number of lines/frequency span

You can use these formulas to determine tradeoffs among the various parameters.

Because the analyzer requires at least one complete time record before it can compute an FFT, the time-record length determines how long a given measurement will take. For example, a 400-line analyzer meas-

uring a 1-kHz span requires a 0.4-sec time record. A 3200-line analyzer requires a 3.2-sec record. This relationship is independent of processing speed. Even with a very-high-speed processor, the 3200-line analyzer must still collect 3.2 sec of data before it can compute the FFT for a 1-kHz span.

After the FFT analyzer has collected a sufficient number of samples (that is, when the time record is full), processing speed does become an issue. The amount of time it takes to compute the FFT and to format and display the results distinguishes the performance of one FFT-based analyzer from another. The available FFT analyzers vary as to how fast they can compute a 400-line FFT. Some models take several milliseconds; others require several minutes.

Processing speed can be important for two reasons. First, higher processing speeds reduce overall test times. The faster the FFT, the less time you spend waiting for a trace on the display. Second, an analyzer's ability to measure transient or dynamic signals is tied directly to its processing speed. The performance indicator is real-time bandwidth, which is the highest frequency the analyzer can measure without missing sections of the incoming signal.

In the analyzer, real-time bandwidth is the frequency span at which the FFT processing speed equals the time-record length. As long as the time-record length is longer than the FFT time, the analyzer will measure every point on the incoming signal. If, however, the time-record length is shorter than the FFT time, the analyzer is sampling faster than it can process, and the analyzer will ignore parts of the signal while the FFT is in progress. Fig 6 illustrates this phenomenon.

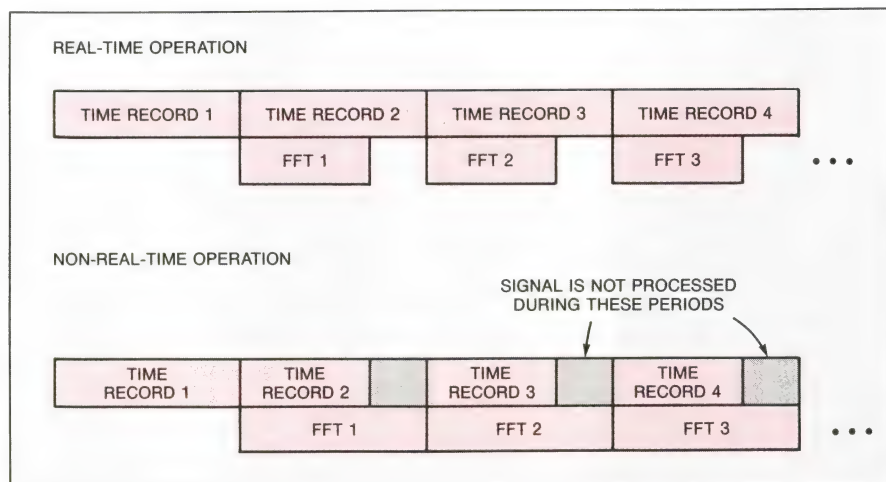


**Fig 6—If the time-record length is shorter than the FFT time, the analyzer is incapable of real-time operation, whereas if the time-record length is at least as long as the FFT time, the analyzer can measure every point on the incoming signal.**



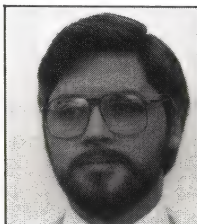
Real-time bandwidth may or may not be a concern for your measurements. If you're measuring a signal that is constant from record to record, the real-time bandwidth is not important because the analyzer doesn't need to see every piece of the signal to make an accurate estimate. If the signal changes from record to record, you need real-time bandwidth, which covers all the frequency components in the signal.

When you're looking for solutions to low-frequency spectrum- and network-analysis problems, remember the five potential advantages of FFT analysis: faster measurements, better frequency resolution, combined spectrum and network analysis, combined time- and frequency-domain capability, and the ability to measure transient signals. Engineers in a wide variety of industries are taking advantage of the FFT measurement technique. It could be the answer to some of your needs as well.

**EDN**

### Author's biography

*George Dovel is a product marketing engineer at Hewlett-Packard's Lake Stevens Instrument Div (Everett, WA), where he develops and implements marketing strategy. George earned a BSEET from the DeVry Institute of Technology in Phoenix, AZ. His leisure pursuits include reading and travel.*



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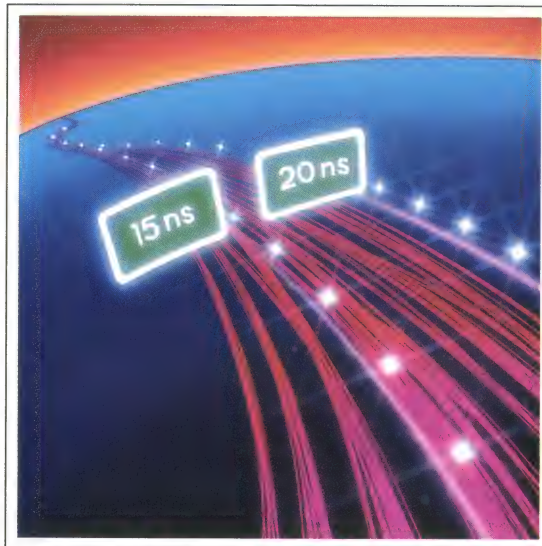
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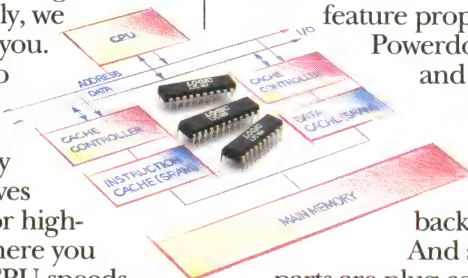
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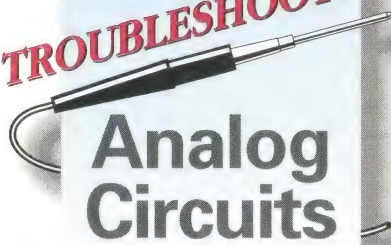
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**TROUBLESHOOTING**



## PART 2

# The right equipment is essential for effective troubleshooting

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*As discussed in part 1 of this multipart series, the most important thing you need for effective troubleshooting is your wits. In addition to those, however, you'll normally want to have some equipment. This second installment itemizes the equipment that is necessary for most general troubleshooting tasks; some you can buy off-the-shelf, and some you can build yourself.*

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Robert A Pease, *National Semiconductor Corp*

Before you begin your troubleshooting task, know that the equipment you use has a direct bearing on the time and effort you must spend to get the job done. Also know that the equipment you need to do a good job depends on the kind of circuit or product you are working on. For example, a DVM may be unnecessary for troubleshooting some problems in digital logic. And, the availability and accessibility of equipment may present certain obstacles. If you only have a mediocre oscilloscope and your company can't go out and buy or rent a fancy full-featured scope, then you will have to make do.

If you lack a piece of equipment, be aware that you are going into battle with inadequate tools; certain

clues may take you much longer than necessary to spot. In many cases when you spent too much time finding one small problem, the time was wasted because you were foolish or were unaware of a particular troubleshooting technique; but, in other cases, the time was wasted because of the lack of a particular piece of equipment. It's important for you to recognize this last-mentioned situation. Learning when you're wasting time because you lack the proper equipment is part of your education as a troubleshooter.

In addition to the proper tools, you also need to have a full understanding of how both your circuit and your equipment are supposed to work. I'm sure you've seen engineers or technicians work for many fruitless hours on a problem and then, when they finally find the solution, say, "Oh, I didn't know it was supposed to work that way." You can avoid this scenario by using equipment that you are comfortable and familiar with.

The following equipment is essential for most analog-circuit troubleshooting tasks. This list can serve as a guide to both those setting up a lab and those who just want to make sure that they have everything they need.

**I**A dual-trace oscilloscope. It's best to have one with a sensitivity of 1 or 2 mV/cm and a bandwidth of at least 100 MHz. Even when you are working with slow op amps, a wide-bandwidth scope is important



*The equipment you want and need to do a good job will depend on the kind of circuit or product you are working on.*

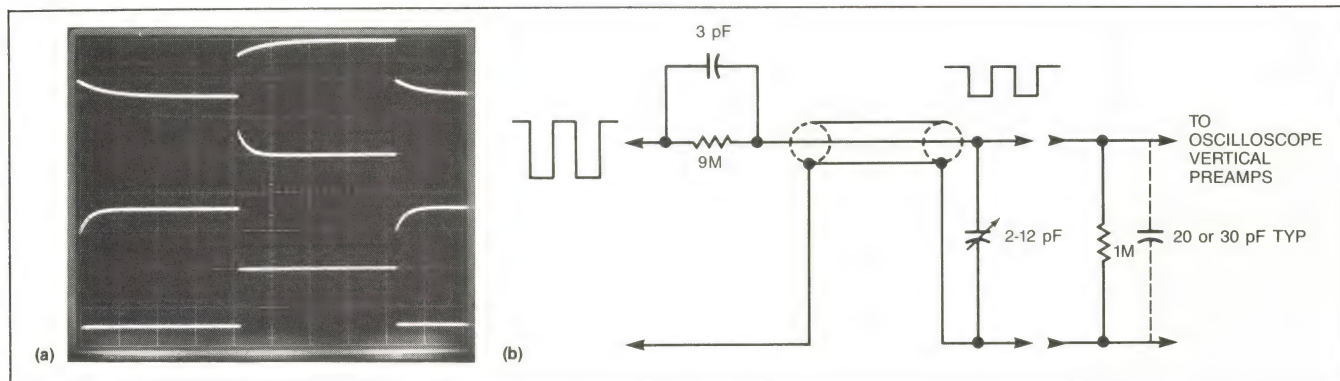


**Fig 1**—If an amplifier or a comparator is supposed to produce a square wave but the waveform looks like **a** trace A or B, how long should it take you to find the problem? No time at all. Just turn the screw that adjusts the 10x probe's compensation, so the probe's response is flat at all frequencies (**a**, trace C). The schematic diagram of a 10x oscilloscope probe is shown in **b**.

because some transistors in "slow" applications can oscillate at 80 or 160 MHz, and you should be able to see these little screams. Of course, when working with fast circuits, you may need to commandeer the lab's fastest scope to look for glitches. Sometimes a peak-to-peak automatic triggering mode is helpful. Be sure you know how all the controls work, so you don't waste much time with setup and false-triggering problems.

**2** Two or three scope probes. They should be in good condition and have suitable hooks or points. Switchable 1x/10x probes are useful for looking at both large and very small signals. You should be aware that 1x probes only have a 16- or 20-MHz bandwidth, even when used with a 100-MHz scope. When you use 10x probes, be sure to adjust the capacitive compensation of the probe by using the square-wave calibrator. Failure to do so can be a terrible time-wasting source of

trouble (**Fig 1**). Ideally, you'll want three probes at your disposal, so that you can have one for the trigger input and one for each channel. For general-purpose troubleshooting, the probes should have a long ground wire, but for high-speed waveforms you'll need to change to a short ground wire (**Fig 2**).

In some high-impedance circuits, even a 10x probe's capacitance, which is typically 9 to 15 pF, may be unacceptable. For these circuits, you can buy an active probe with a lower input capacitance of 1.5 to 3 pF (\$395 to \$1800), or you can build your own (**Fig 3**).

**3** An analog-storage oscilloscope. Such a scope can be extremely useful, especially when you are searching for an intermittent or evanescent signal. The scope can trigger off an event that may occur only rarely and can store that event and the events that follow it. Some storage scopes are balky or tricky to

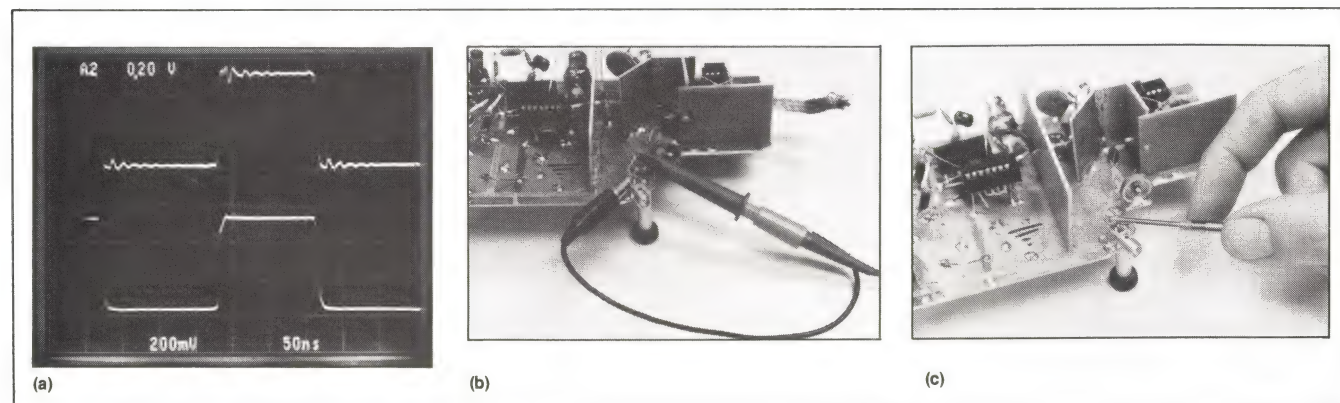


**Fig 2**—When a fast square wave is supposed to be clean and fast-settling but looks like **a**, trace A, don't repair the square-wave generator—just throw away the probe's 6-in. ground lead (**b**). If you ground the probe directly at the ground point near the tip (**c**) (special attachments that bring the ground out conveniently are available), your waveforms will improve (**a**, trace B).



apply, but it's often worthwhile to expend the effort to learn how to use them.

Digital-storage oscilloscopes (DSOs) let you do the same type of triggering and event storage as do the analog type, and some can display events that precede the trigger. They are sampled-data systems, however, so you must be sure to apply them correctly (Ref 1). Once you learn how to use them, though, you'll appreciate the special features they offer, such as bright CRT displays, automatic pulse-parameter measurements, and the ability to obtain plots of waveforms.

**4**A digital voltmeter (DVM). Choose one with at least five digits of resolution, such as the HP3455, the HP3456, the Fluke 8810A, and the Fluke 8842A. Be sure you can lock out the autorange feature, so that the unit can achieve its highest accuracy and speed. Otherwise, you'll be wasting time while the DVM autoranges. For many analog circuits, it's important to have a high-impedance ( $>10,000\text{-M}\Omega$ ) input that can handle 15 to 20V; the four DVMs mentioned above have this feature. There are many other fine DVMs that have  $10\text{-M}\Omega$  inputs above 2 or 3V; and, if a  $10\text{-M}\Omega$  input impedance is not a problem, they are acceptable.

The most important reason to use a high-input-

impedance DVM is because sometimes it's necessary to put  $33\text{-k}\Omega$  or  $100\text{-k}\Omega$  resistors in series with the probe, right near the circuit-under-test, to prevent the DVM's input capacitance from causing the circuit to oscillate. If you're using a DVM with a  $10\text{-M}\Omega$  input impedance and you have a  $100\text{-k}\Omega$  resistor in series with the probe, the DVM's measurements would lose 1% of their accuracy. Fortunately, many good DVMs have less than 500 pA of input current, which would cause less than  $50\text{ }\mu\text{V}$  of error in the  $100\text{-k}\Omega$ -load case.

A high-resolution DVM lets you detect 100- to  $200\text{-}\mu\text{V}$  deviations in an 11V signal. You can best spot many semiconductor problems by finding these minor changes. A 4-digit DVM is a relatively poor tool; although, in some cases, you can detect small voltage changes if you refer the DVM's "low," or ground, side to the 10V bus. Then, with the DVM in the 1V range, you can spot small deviations in an 11V signal. This measurement is more awkward and inconvenient than a ground-referenced measurement with a higher resolution meter would be, and this method can cause other problems as well. For instance, you can end up injecting noise generated by the DVM's A/D converter into the sensitive 10V reference, thereby adversely affecting the performance of other circuits.

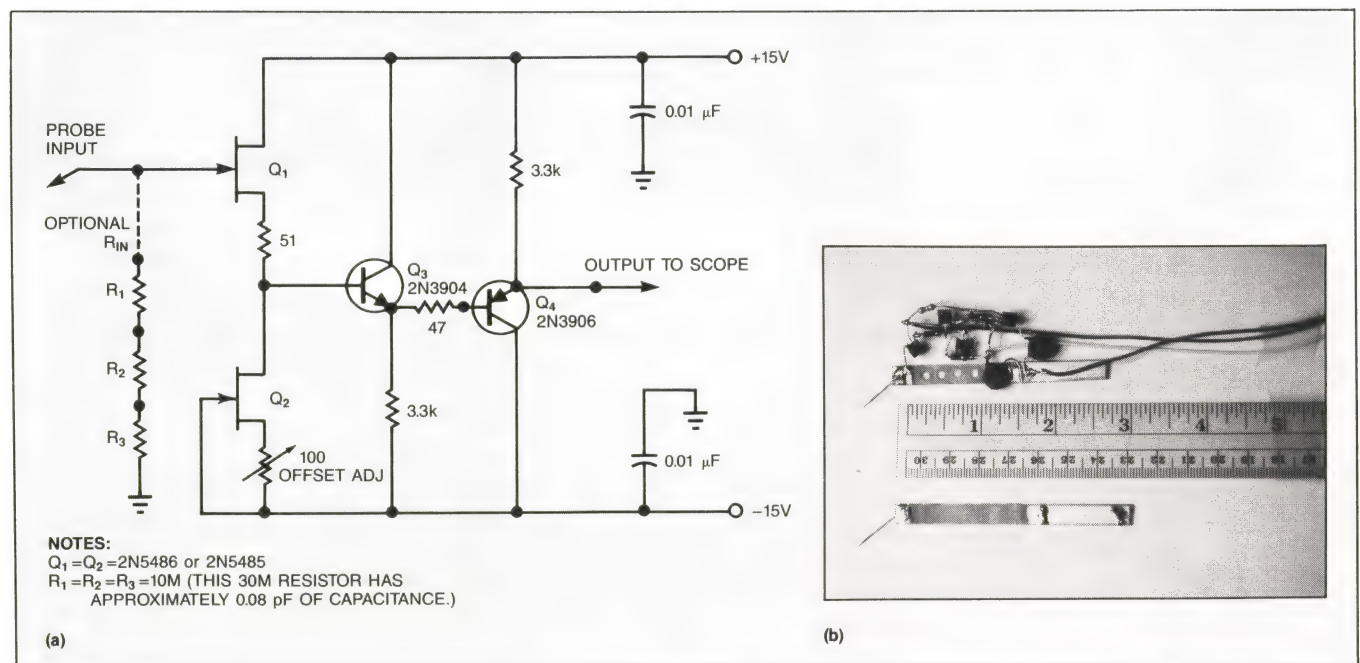


**Fig 3—This probe circuit's input impedance is  $10^{11}\Omega$  in parallel with  $0.29\text{ pF}$  (a). Optimized for its impedance characteristics and not its frequency response, the probe's bandwidth and slew rate are 90 MHz and  $300\text{V}/\mu\text{sec}$ , respectively. If the lack of physical rigidity of the TO-92 packaged FET makes it difficult to use as a probe, a piece of  $1/16\text{-in.}$  glass epoxy board with the copper peeled off will add rigidity with only  $0.08\text{ pF}$  of additional capacitance. The layout shown in b adds only  $0.06\text{ pF}$  to the input impedance.**



*If you lack a piece of equipment, be aware that you are going into battle with inadequate tools.*

**5** Auxiliary meters. It may look silly to see a test setup consisting of two good DVM's, two little 3-digit DVMs monitoring a couple of voltage supplies, a couple more 3-digit DVMs monitoring current drain, and an analog meter monitoring something else. But, if you don't know exactly what you're looking for and you can borrow equipment, using lots of meters is an excellent way to attack a problem—even if you do have to wait until 5:15 pm to borrow all that equipment.

When is an analog voltmeter better than a DVM? Well, the analog voltmeter usually has inferior accuracy and resolution, but when you watch an ordinary analog voltmeter your eye can detect a trend or rate-of-change that may be hard to spot on a DVM, especially in the presence of noise or jitter. As an example, if you suddenly connect an ordinary volt-ohmmeter across a 1- $\mu$ F capacitor, your eye can resolve if the capacitor's value is 0.1 times or 10 times as large as it should be. You can't perform this kind of test with a DVM.

Another advantage of analog meters is that they are passive devices: They don't inject noise into your circuit as digital meters can.

**6** A general-purpose function generator. In addition to supplying the drive signal for your circuit, you can use function generators to feed current via a resistor into a node while you check for the correct circuit response. While sine and square waves are popular test signals, I have often found triangular waveforms to be invaluable when searching for nonlinearities.

**7** Power supplies with stable outputs. They should have coarse and fine adjustment controls and adjustable current limits. Digital controls are usually not suitable; they don't let you continuously sweep the voltage up and down while you monitor the scope and watch for trends. In cases when the power supply's output capacitor causes problems, you may want a power supply whose output circuit, like that of an op amp, includes no output capacitor. You can buy such a supply, or you can make it with an op amp and a few transistors. The advantage of the supply shown in Fig 4 is that you can design it to slew fast when you want it to. Also, if a circuit latches and pulls its power supply down, the circuit won't destroy itself by discharging a big capacitor.

Along the lines of power, another useful troubleshooting tool is a set of batteries. You can use a stack of one, two, or four 9V batteries, gel cells, or whatever is convenient. Batteries are useful as an alternate power supply for low-noise preamplifiers. If the preamp's output doesn't get quieter when the batteries are substituted for the ordinary power supply, don't blame your circuit troubles on the power supply. You can also use these batteries to power low-noise circuits, such as those sealed in a metal box, without contaminating their signals with any external noise sources.

**8** A few RC substitution boxes. You can purchase the VIZ Model WC-412A "twiddle-box" (Fig 5) from Fordham Radio (Hauppauge, NY). You can set the

**Fig 4—You can vary the output voltage of this dc power supply from 3 to 30V by adjusting  $R_1$ .  $R_{sc}$  should be between 3 and 100 $\Omega$ ; the short-circuit current is equal to  $600\text{mV}/R_{sc} + 20\text{mA}$ .**

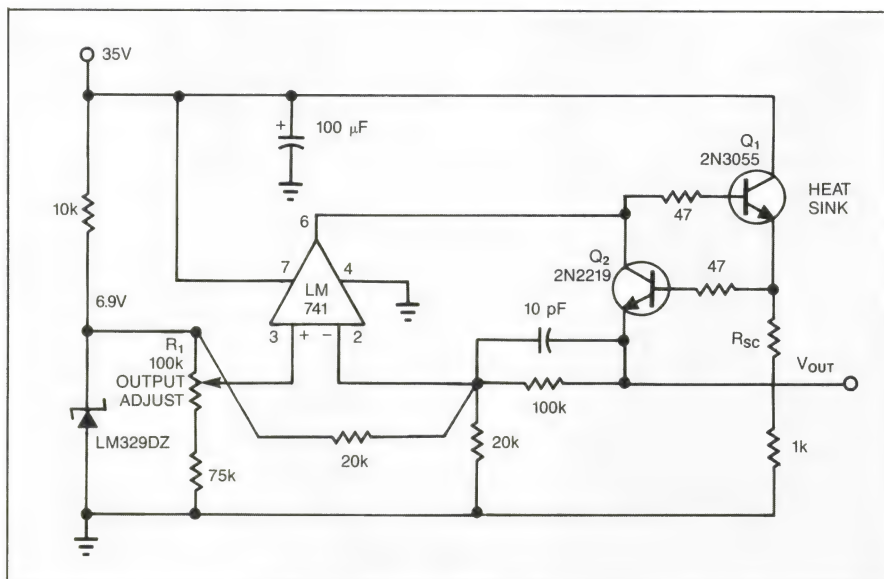
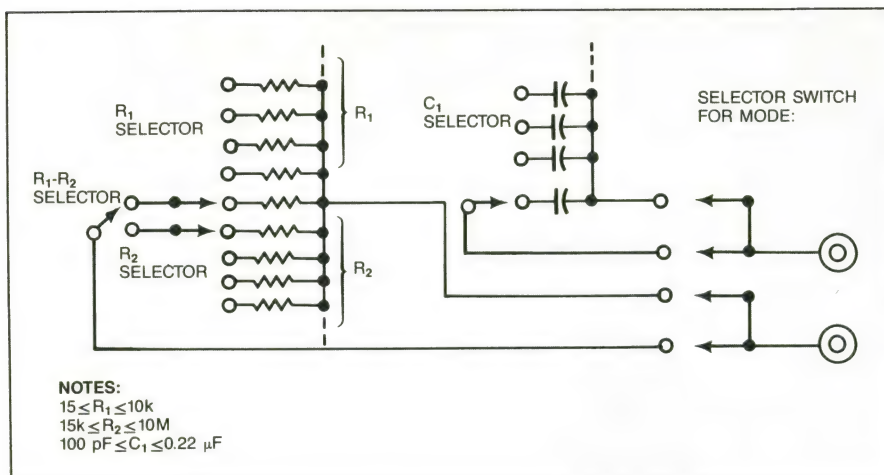




**Fig 5—This general schematic is for a commercially available R-C substitution box, the VIZ Model WC-412A from Fordham Radio (Hauppauge, NY). The unit costs around \$89 and has resistor and capacitor values in the range of  $15\Omega$  to  $10\text{ M}\Omega$  and  $100\text{ pF}$  to  $0.2\text{ }\mu\text{F}$ , respectively. It can be configured to be an open circuit, a series R-C, resistors, capacitors, a parallel R-C, or a short circuit.**



unit in the following modes: R, C, series R-C, parallel R-C, open circuit, or short circuit. They are invaluable for running various “tests” that can lead to the right answer.

You may need component values beyond what the twiddle boxes offer; in our labs, we built a couple of home-brew versions (Fig 6). The circuit shown in Fig 6a provides variable low values of capacitance and is useful for fooling around with the damping of op amps and other delicate circuits. You can make your own calibration labels to mark the setting of the capacitance and resistance values. The circuit shown in Fig 6b provides high capacitance for testing power supplies and damping various regulators.

**9** An isolation transformer. If you are working on a line-operated switching regulator, this transformer helps you avoid lethal and illegal voltages on your test setup and on the body of your scope. If you have trouble obtaining an isolation transformer, you can use a pair of transformers (step-down, step-up) back-to-back (Fig 7). Or, if cost isn’t an issue, you can use isolated probes. These probes let you display small signals that have common-mode voltages of hundreds of volts with respect to ground, and they won’t require

you to wear insulated gloves when adjusting your scope.

**10** A variable autotransformer. This instrument lets you change the line voltage and watch its effect on the circuit. (Warning: A variable auto-transformer is NOT normally an isolation transformer.)

**11** A curve tracer. A curve-tracer can show you that two transistors may have the same saturation voltage under a given set of conditions even though the slope of one may be quite different from the slope of the other. If one of these transistors works well and the other badly, a curve tracer can help you understand why. A curve tracer can also be useful for spotting nonlinear resistances and conductances in diodes, capacitors, light bulbs, and resistors. It can test a battery by loading it down or recharging it and can check semiconductors for breakdown. And, when you buy the right adapters or cobble them up yourself, you can evaluate the shape of the gain, the CMRR, and the PSRR of op amps.

**12** Spare repair parts for the circuit-under-test. You should have these parts readily available, so you

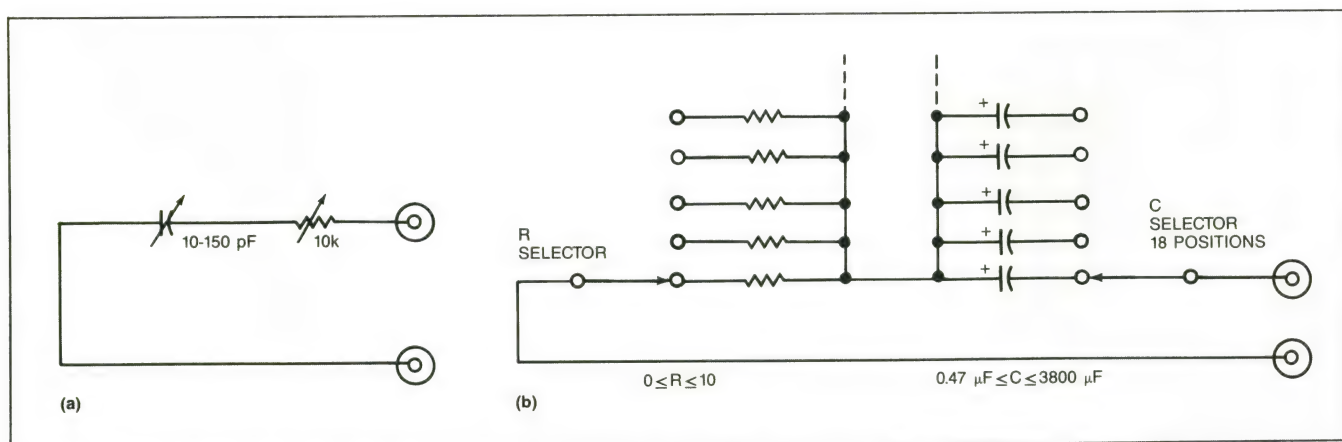


**Fig 6—R-C boxes based on these schematics extend component ranges above those available in off-the-shelf versions. You can house the series R-C circuit in **a** in a  $1 \times 1 \times 2$ -in. copper-clad box. Use the smaller plastic-film-dielectric tuning capacitors or whatever is convenient. Build the circuit in **b** with tantalum or electrolytic (for values of  $1\text{ }\mu\text{F}$  and higher) capacitors, but remember to be careful about their polarities and how you apply them. Also, you might consider using mylar capacitors for smaller values. Use 18-position switches to select R and C values. And, stay away from wirewound resistors; their inductance is too high.**



a 100-M $\Omega$  resistor doesn't mean that these values won't be helpful in troubleshooting it. Similarly, you may not have a big capacitor in your circuit; but, if the circuit suddenly stops misbehaving when you put a 3800- $\mu$ F capacitor across the power supply, you've seen a quick and dramatic demonstration that power-supply wobbles have a lot to do with the circuit's problems. Also, several feet of plastic-insulated solid wire come

**13** A complete supply of resistors and capacitors. You should have resistors in the range from 0.1Ω to 100 MΩ and capacitors from 10 pF to 1μF. Also, 10-, 100-, and 1000-μF capacitors come in handy. Just because your circuit design doesn't include a 0.1-Ω or

A short-circuit-detector circuit comes in handy when you have to repair a lot of large pc boards: It can help you find a short circuit between the ground bus and the power or signal buses. It's true that a sensitive DVM can also perform this function, but a short-circuit detector is much faster and more efficient. Also, the circuit turns itself off and draws no current when the probe is not connected.

In the short-circuit-detector circuit shown in **Fig A**, the LM10

op amp amplifies the voltage drop and feeds it to the LM331 voltage-to-frequency converter, which you set up to emit its highest pitch when  $V_{in}=0$ . When using this circuit, use a 50-to 100-mA current-limited power supply. To calibrate the circuit, first ground the detector's two probes and trim the OFFSET ADJUST for a high pitch. Then, move the positive test probe to  $+V_s$  at A and trim the GAIN ADJUST for a low pitch.

**Fig A** illustrates a case in

which one of the five major power supply buses of the circuit-in-trouble has a solder short to ground. To find the exact location of the short, you simply slide the positive input probe along the buses. In this example, if you slide it from A toward B or D, the pitch won't change because there is no change in voltage at these points. But, if you slide the probe along the path from A to C or from K to M, the pitch will change because the voltage drop is changing along those paths.

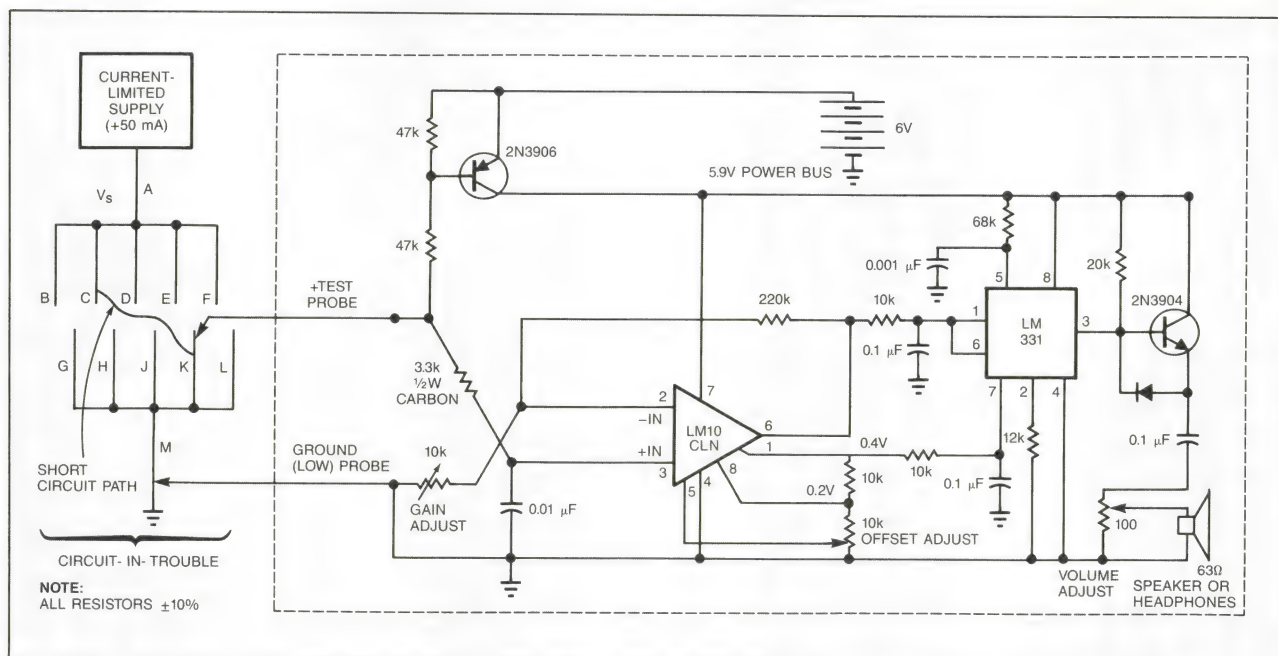


**Fig A**—You can use this short-circuit detector to find PCB shorts. Simply slide the test probe along the various buses and listen for changes in pitch.



*Be familiar with your equipment: Know how to use it and know its limitations.*

in handy. A few inches of this type of twisted-pair wire makes an excellent variable capacitor, sometimes called a "gimmick." Gimmicks are cheap and easy to vary by simply winding or unwinding them. Their capacitance is approximately 1 pF/in.

**14** Schematic diagrams. It's a good idea to have several copies of the schematic of the circuit-under-test. Mark up one copy with the normal voltages, currents, and waveforms to serve as a reference point. Use the others to record notes and waveform sketches that relate to the specific circuit-under-test. You'll also need a schematic of any homemade test circuit you plan to use. Sometimes, measurements made with your homemade test equipment may not really agree with measurements made by purchased test equipment. The results from each tester may not really be "wrong;" they might differ because of some design feature, such as signal filtering. If you have all the schematics for your test equipment, you can more easily explain these incompatibilities. And, finally, the data sheets and schematics of any ICs used in the circuit will also come in handy.

**15** Access to any engineering or production test equipment, if possible. Use this equipment to be sure that when you fix one part of the circuit you aren't adversely affecting another part. Other pieces of equipment and testers also fall under the category of specialized test equipment; their usefulness will depend on your circuit. Two examples are a short-circuit-detector circuit (see **box**, "A short-circuit detector aids

PCB repair") and a grid-dip meter (see **box**, "The grid-dip meter can direct you to trouble").

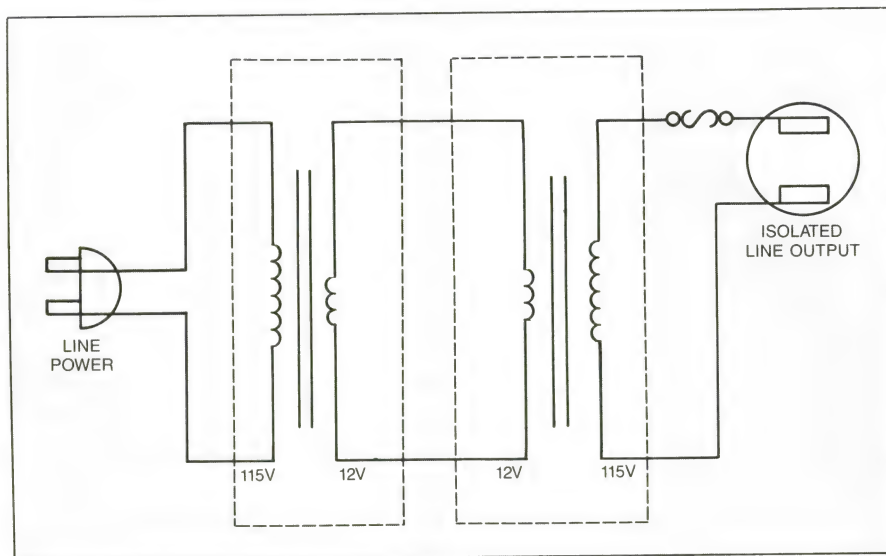
**16** A few working circuits, if available. By comparing a bad unit to a good one, you can often identify problems. You can also use the good circuits to make sure that your specialized test equipment is working properly.

**17** A sturdy, broad workbench. It should be equipped with a ground plane of metal that you can easily connect to the power ground. The purpose of this ground plane is to keep RF, 60-Hz, and all other noise from coupling into the circuit. Place insulating cardboard between the bench and the circuit-under-test, so that nothing tends to short to ground. Another way to prevent noise from interfering with the circuit is to use a broad sheet of single-sided copper-clad board. Placed copper-side down and with a ground wire soldered to the copper, it provides an alternate ground plane. To prevent electrostatic-discharge damage to CMOS circuits, you'll need a wrist strap to ground your body through 1 M $\Omega$ .

**18** Safety equipment. When working on medium- or high-power circuits that might explode with considerable power in the case of a fault condition, you should be wearing safety goggles or glasses with safety lenses. Keep a fire extinguisher nearby, too.

**19** A suitable hot soldering iron. If you have to solder or unsolder heavy buses from broad PCB

**Fig 7—You can use this back-to-back transformer configuration to achieve line isolation similar to that of an isolation transformer.**





## The grid-dip meter can direct you to trouble

What do you do when trouble is everywhere? A typical scenario starts out like this: You make a minor improvement on a linear circuit, and when you fire it up you notice a terrible oscillation riding on the circuit's output. You check everything about the circuit, but the oscillation remains. In fact, the oscillation is riding on the output, the inputs, on several internal nodes, and even on ground. You turn off the DVM, the function generator, the soldering iron, and the power supplies; but the oscillation is still there.

Now you start looking around the lab to see who has started a new oscillator or switching regulator that is doubling as a medium-power transmitter. Aside from yelling, "Who has a new circuit oscillating at 87 kHz?" what can you do to solve the problem? One useful tool is an ordinary AM transistor radio. As we have all learned, FM radios reject many kinds of noise, but AM radios scoop up noise at repetition rates and frequencies that would surprise you.

How can a crummy little receiver with an audio bandwidth of perhaps 5 kHz detect noise in the kilohertz and megahertz regions? Of course, the answer is that many repetitive noise-pulse trains, whose repetition rates are higher than the audible spectrum but below the AM frequency band, have harmonics that extend into the vicinity of 600 kHz, where the AM receiver is quite sensitive. This sensitivity ex-

tends to signals with amplitudes of just a few microvolts.

If you are skeptical about an AM radio's ability to detect these signals, tune the low end of an AM radio dial between stations. Then, place it near a DVM or a computer and listen for the hash. Notice, too, that the ferrite stick antenna has definite directional sensitivity, so you can estimate where the noise is coming from by using either the null mode or pointing the antenna to get the strongest signal. So, the humble AM radio may be able to help you as you hike around the lab and smile pleasantly at your comrades until you find the culprit whose new switching regulator isn't working quite right but which he neglected to turn off when he went out to get a cup of coffee.

On other occasions, the frequency and repetition rate of the noise are so high that an AM receiver won't be helpful in detecting the problem. What's the tool to use then? Back in the early days of radio, engineers found that if you ran a vacuum-tube oscillator and immersed it in a field of high-power oscillations at a comparable frequency, the tube's grid current would shift or dip when the frequencies matched. This tool became known as the "grid-dip meter." I can't say that I am an expert in the theory or usage of the grid-dip meter, but I do recall being impressed in the early days of monolithic ICs: A particular linear circuit was oscillating at 98 MHz, and the grid-dip

meter could tickle the apparent rectified output error as I tuned the frequency dial back and forth.

That was 20 years ago, and, of course, Heathkit has discontinued their old Grid Dip and Tunnel Dip meters in favor of a more modern design. The new one, simply dubbed "Dip Meter," uses transistors and tetrode FETs. At the bargain price of \$89, every lab should have one. They'll help you ferret out the source of nasty oscillations as high as 250 MHz. The literature that comes with the HD-1250 dip-meter kit also lists several troubleshooting tips.

When grid-dip meters first became popular, the fastest oscilloscope you could buy had a bandwidth of only a few dozen megahertz. These days, it is possible to buy a scope with a bandwidth of many hundreds of megahertz, so there are fewer occasions when you might need a grid-dip meter. Still, there are times when it is exactly the right tool. For example, you can use its oscillator to activate passive tuned circuits and detect their modes of resonance. Also, in a small company where you can't afford to shell out the many thousands of dollars for a fast scope, the Dip Meter is an inexpensive alternative.



*Don't forget about safety: Wear goggles when working on high-power circuits and keep a fire extinguisher near your workbench.*

(pc-board) traces, use a big enough iron or gun. For small and delicate traces around ICs, a small tip is essential. And, be sure that the iron is hot enough. An easy way to delaminate a trace or pad, whether you want to or not, is to heat it for too long a time. (The old Heathkit warnings not to use a hot iron became obsolete along with the germanium transistor.) In some cases, a grounded soldering iron is required; in others, a portable (ungrounded or rechargeable) soldering iron is ideal. Make sure you know whether your iron is grounded or floating.

**20** Tools for removing solder, such as solder wick or a solder sucker. You should be comfortable with whatever tools you are using; a well-practiced technique is sometimes critical for getting good results. If you are working on static-sensitive components, an antistatic solder sucker is less likely to generate high voltages due to internal friction than is a conventional solder sucker. I have been cautioned that a large solder

sucker may cause problems when working on narrow PCB traces; in that case, solder wick may be the better choice.

**21** Hand tools. Among the tools you'll need are sharp diagonal nippers, suitable pliers, screwdrivers, large cutters, wrenches, wire-strippers, and a jack knife or Exacto knife.

**22** Signal leads, connectors, cables, BNC adapters, wires, clip leads, ball hooks, and alligator clips—as needed. Scrimping and chintzing in this area can waste lots of time: shaky leads can fall off or short out.

**23** Freeze mist and a hair dryer. The freeze mist available in aerosol cans lets you quickly cool individual components. A hair dryer lets you warm up a whole circuit. You'll want to know the dryer's output air temperature because that's the temperature to which you'll be heating the components.

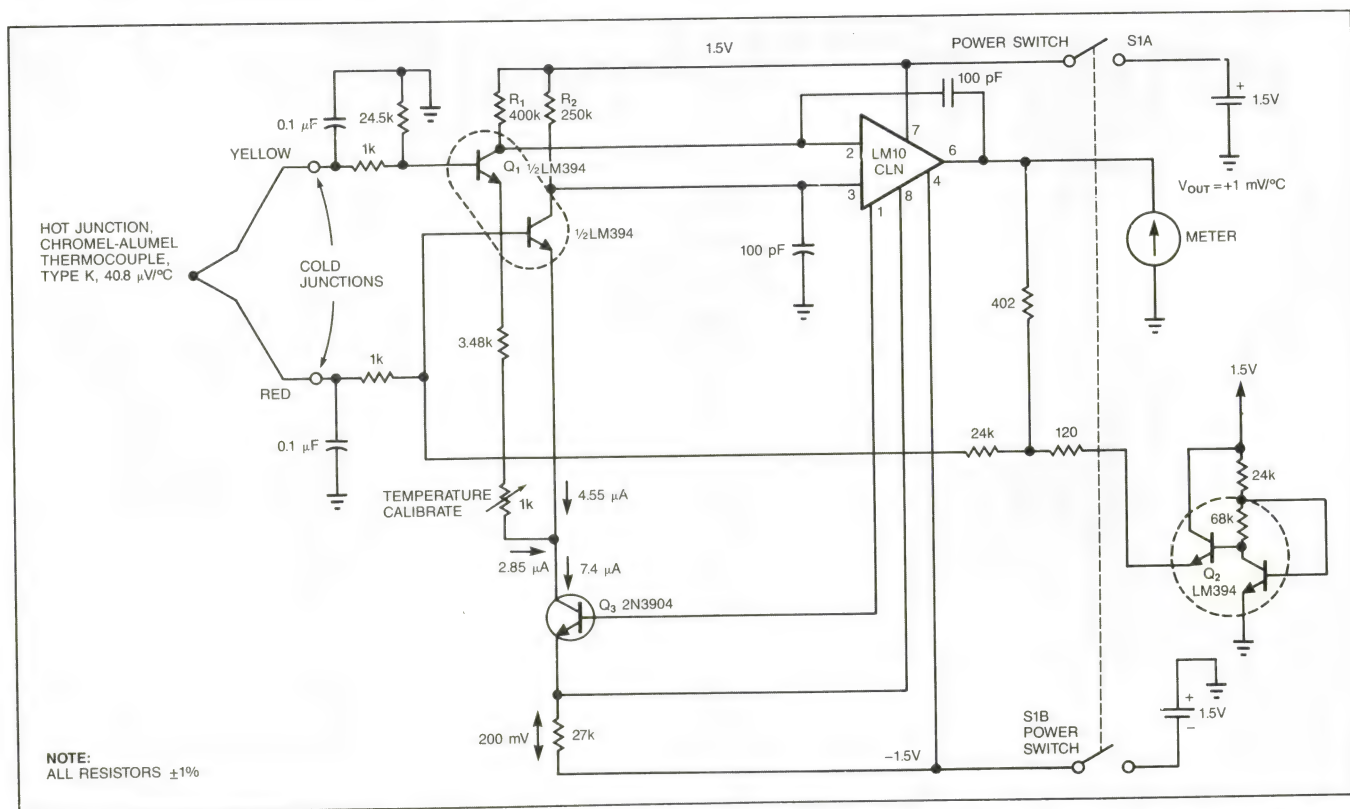


**Fig 8—This thermocouple amplifier** has inherent cold-junction compensation because of the two halves of  $Q_1$ , which run at a 1.6:1 current ratio. Their  $V_{BE}$ s are mismatched by  $12\text{ mV} + 40.8\text{ }\mu\text{V}/^\circ\text{C}$ . This mismatch exactly cancels out the  $40.8\text{ }\mu\text{V}/^\circ\text{C}$  of the cold junction. For best results, you should use four  $100\text{-k}\Omega$  resistors in series for  $R_1$  and two  $100\text{-k}\Omega$  resistors in series with two  $100\text{-k}\Omega$  resistors in parallel for  $R_2$ .  $Q_2$  and its surrounding components implement a correction for very cold temperatures and are not necessary for thermocouple temperatures above  $0^\circ\text{C}$ . (Credit goes to Mineo Yamatake for his elegant circuit design.)



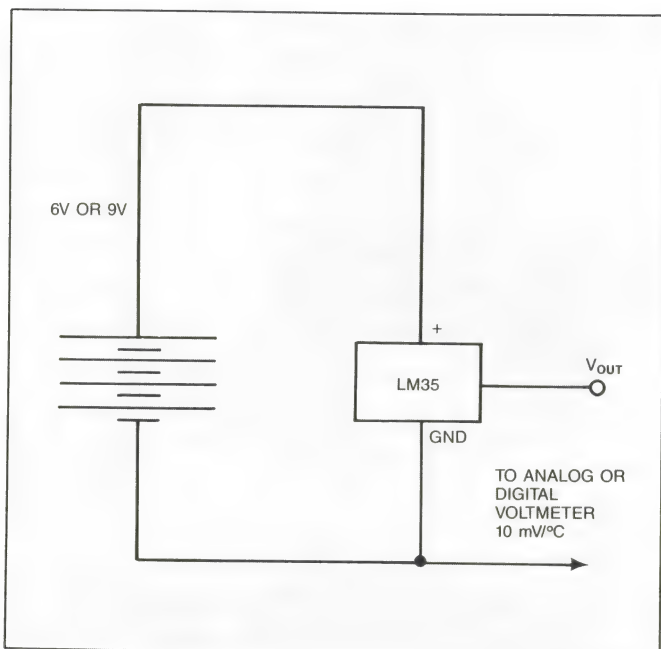


**Fig 9—Beware of using this circuit** to measure the temperature of very small objects; it will give you less accurate readings than a tiny thermocouple with small wires.

**24** A magnifying glass or hand lens. These devices are useful for inspecting boards, wires, and components for cracks, flaws, hairline solder shorts, and cold-soldered joints.

**25** An incandescent lamp or flashlight. You should be able to clearly see what you are doing, and bright lights also help you to inspect boards and components.

**26** A thermocouple-type thermometer. If your thermometer is floating and battery powered, you can connect the thermocouple to any point in the circuit and measure the correct temperature with virtually no electrical or thermal effect on the circuit. **Fig 8** shows a thermocouple amplifier with designed-in cold-junction compensation.

Some people have suggested that an LM35 temperature-sensor IC (**Fig 9**) is a simple way to measure temperature, and so it is. But, if you touch or solder an LM35 in its TO-46 package to a device in a TO-5 or TO-3 case, the device's leads will increase the thermal mass and conduct heat away from the device whose temperature you are trying to measure. Thus, your measurements will be less accurate than if you had used a tiny thermocouple with small wires.

You've come to the end of my list of essential equipment for ordinary analog-circuit troubleshooting. Depending on your circuit, you may not need all these items; and, of course, the list did not include a multitude of other equipment that you may find useful. Logic analyzers, impedance analyzers, spectrum analyzers, programmable current pumps, capacitance meters and testers, and pulse generators can all ease various troubleshooting tasks.

Each of you will have your own idea of what is essential and what is unnecessary for your special case, and I would be delighted to get feedback on this subject. You can write to me at Mail Stop C2500A, National Semiconductor Corp, Box 58090, Santa Clara, CA 95052.

**EDN**

## References

1. Collins, Jack, and David White, "Time-domain analysis of aliasing helps to alleviate DSO errors," *EDN*, September 15, 1988, pg 207.

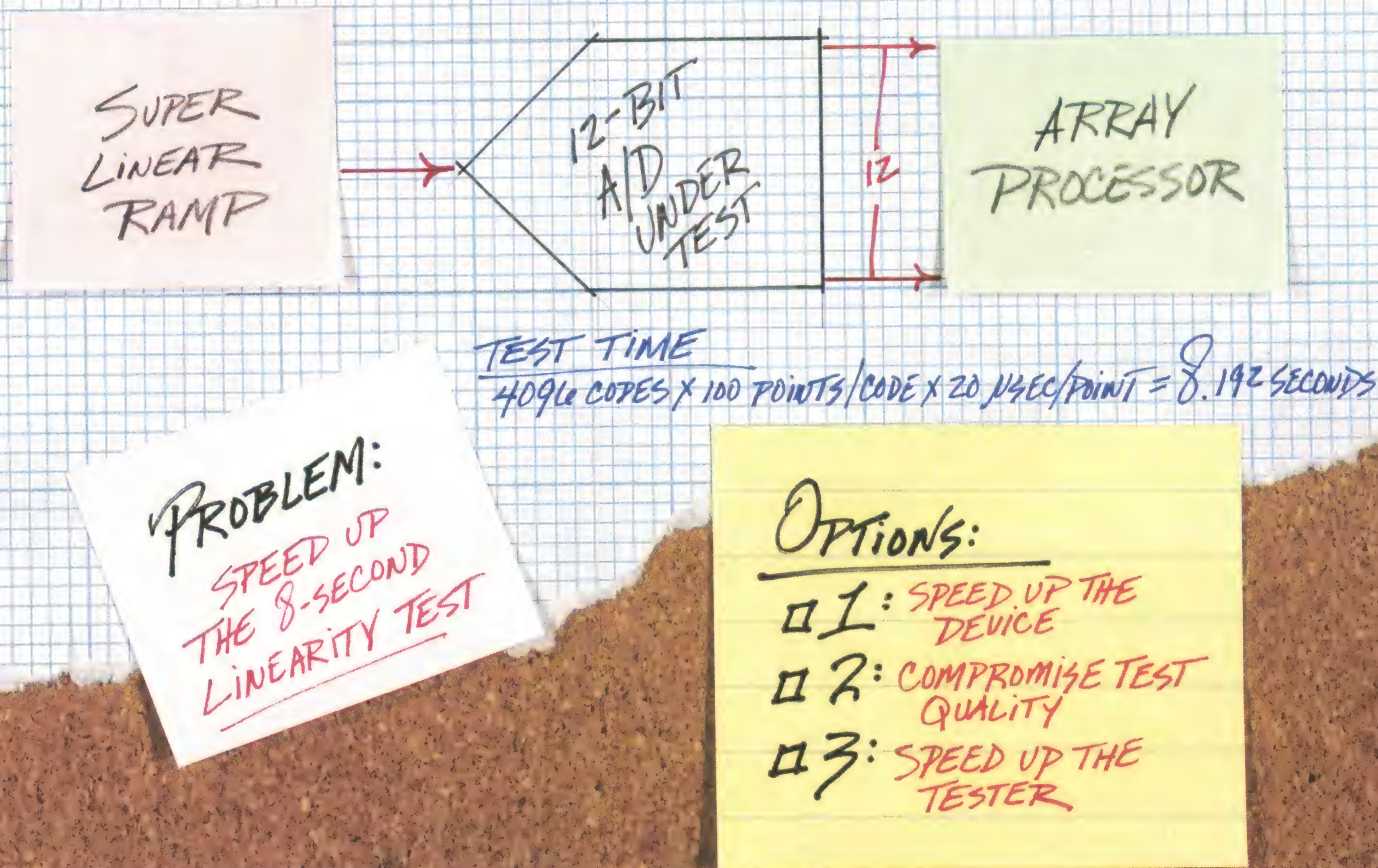
## Author's biography

For information about Bob Pease, see the box, "Who is Bob Pease, anyway?" in the January 5, 1988, edition of *EDN*.

Article Interest Quotient (Circle One)  
High 491 Medium 492 Low 493



# 1 is impossible. 2 is undesirable. 3 is...



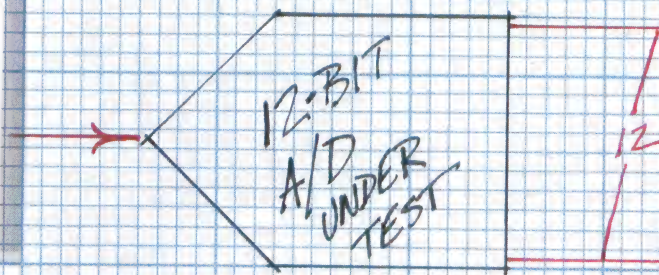
The choices don't appear to be very attractive, but the problem must be solved. An eight-second test time for all-code differential and integral non-linearity testing is out of the question for production testing. And it gets worse geometrically for higher-order converters: A 16-bit device would take 128 seconds.

What about your options? The A/D already spits out numbers ten times as fast as most testers can process them — especially with the single, general-purpose array processor typically used for this test. Testing less codes or reducing the amount of averaging would seriously diminish test quality.

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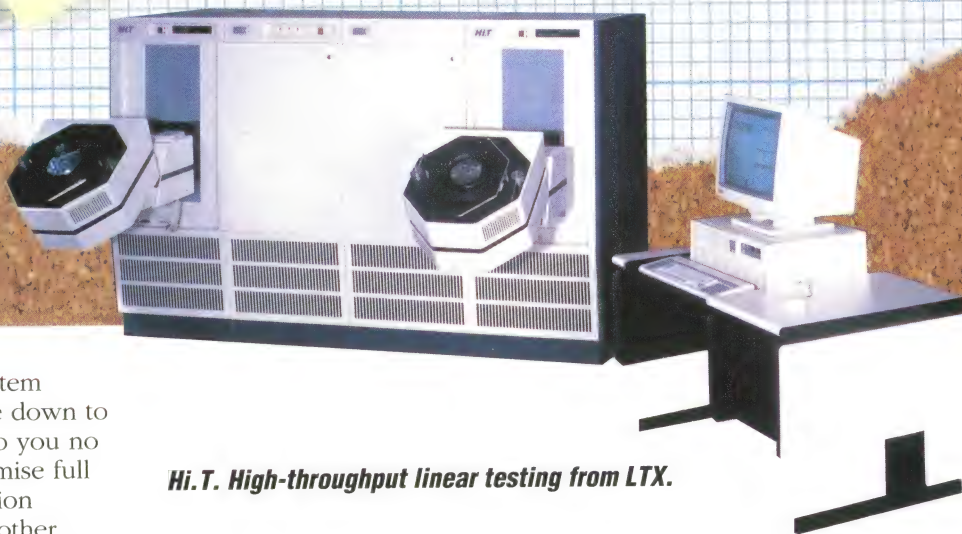
Hi.T, the high-throughput tester from LTX, gets a tenfold speed boost through a new technique: a local Digital Signal Accelerator that reads the A/D's output directly and does the bulk of the calculation on the fly. Which leaves the downstream array processor to compute results on one tenth the original data — in one tenth the time of other testers.



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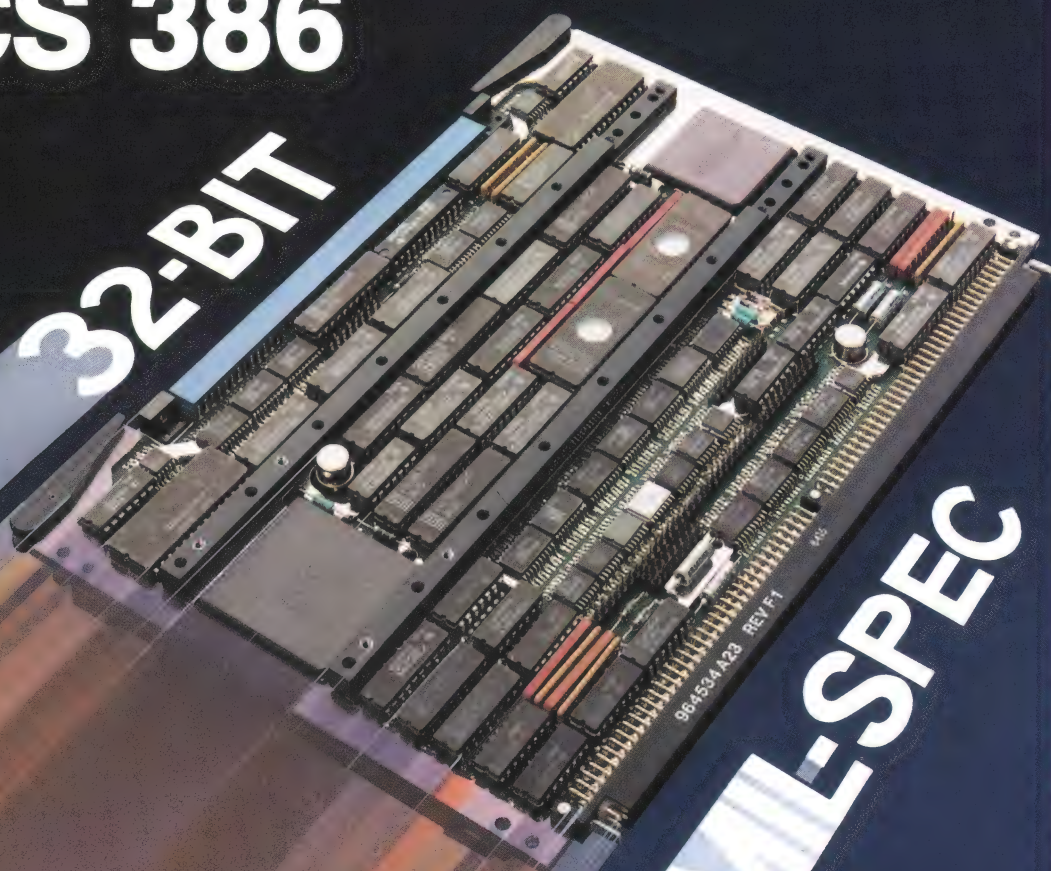
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# Drive scheme holds key to dc motor performance

*To optimize the performance of a brushless dc servomotor system, you must select the proper motor drive scheme. Two popular drive options, the 6-step and the sine-wave designs, illustrate how output torque, current ripple, and PWM techniques can affect system performance.*

Malcolm B McCormick, *Inland Motor*

The key to understanding and using brushless dc motor and amplifier systems involves commutation—knowing both when and how much voltage to apply to which motor phase in order to obtain the desired rotation and torque in the right direction. And selecting the right sensors and understanding the motor's specific design are both prerequisites to truly reliable commutation for a brushless dc servomotor.

Sensors that are assigned to specific rotor positions determine the timing-control aspect of commutation. These devices may be magnetic or optical, but they must provide sufficiently accurate, reliable information on the position of the motor rotor.

How much voltage to apply during commutation depends on the motor's design. In some cases, how much voltage may mean all of the voltage available. There are 2 predominant commutation schemes at present—

the 6-step (or square-wave or trapezoidal) and the sinusoidal (or sine-wave) designs. Because the 6-step configuration is the simpler of the two to implement, it's a good place to start examining the relationship between motor design and commutation.

## Taking it step by step

For 6-step commutation, **Fig 1** shows a typical back-EMF waveform for a brushless dc motor. It consists of three sinusoidal voltages— $V_{AB}$ ,  $V_{BC}$ , and  $V_{CA}$ —which are evenly spaced in time. From an electrical standpoint, these sine waves repeat themselves every 360° and are spaced 120° apart. The actual number of cycles per physical rotation of the rotor depends on the specific motor design. (Although this example shows a 3-phase motor waveform, the rules apply to motors with any number of phases.)

Torque performance varies with rotor position. A

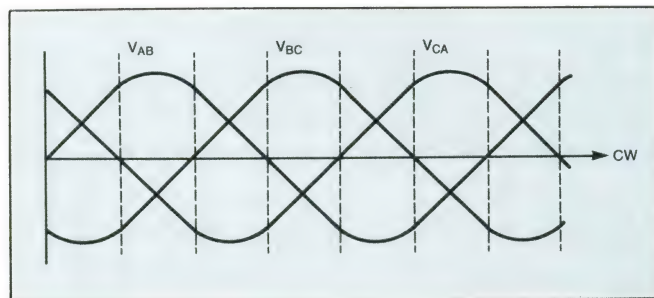


**Fig 1—A typical back-EMF waveform for a brushless dc motor consists of three sinusoidal voltages. The dotted lines designate the peak torque regions.**



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## *A motor's design determines how much voltage to apply during commutation.*

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motor's ability to generate torque exhibits the same wave shape as the motor's back-EMF waveform. This fact holds true for any shape of back-EMF waveform. It's important to remember this point when applying brushless dc motor amplifiers because the back-EMF wave shape, combined with a need for a constant torque regardless of rotor position, may make some interesting and difficult demands on the amplifiers.

The correlation between a motor's ability to generate torque and the shape of its back-EMF waveform also means that applying voltage to phases A and B ( $V_{AB}$ ) when the rotor is in a position corresponding to the zero crossing of  $V_{AB}$  obviously yields no torque at all. For the waveforms shown in **Fig 1**, you must apply the voltage in the peak back-EMF regions to develop peak torque and to properly commutate a motor. The vertical dotted lines on the back-EMF waveform diagram in **Fig 1** designate the peak torque regions.

**Fig 2** shows the outputs of Hall-effect devices— $H_{AB}$ ,  $H_{BC}$ , and  $H_{CA}$ . These devices sense the magnetic field of the rotor that's also generating the motor's back-EMF waveforms. Note that the outputs of the Hall-effect devices correspond to the zero crossings of the back-EMF waveforms. Note too that when  $V_{AB}$  is positive,  $H_{AB}$  is also positive.

Manufacturers differ in the way they set up the relationship between a rotor-position sensor and the motor phase, and you should know precisely which relationship a manufacturer is supplying. You can logically combine the rotor-position-sensor outputs to yield 6 separate commutation sectors, which are indicated as position sectors in **Fig 3**. In this case, the sector (or state) numbering shown is specific to Inland products.

**Fig 4** shows power transistors arranged in a totem-pole configuration and connected to a power supply and to phases A, B, and C of the motor. The excitation

table in **Fig 3** shows which transistors turn on as a function of the outputs of the rotor-position sensors. Note that the 6-step commutation function takes advantage of the negative portions of the back-EMF waveforms as well as the positive ones. By reversing the phase polarity, you can make use of all torque peaks. The 6-step commutation process starts with sector 1, goes through to sector 6, and then repeats.

### **Don't neglect torque variations**

Remember that torque varies with rotor position. Since the 6-step commutation scheme applies a square-wave voltage each time the motor commutates, the shape of the back-EMF waveform—as well as the motor's magnetic circuit—determines the amount of torque ripple that occurs during one motor revolution. While commutation-only controller designs are sufficient for many applications, designers must be aware of the potential for torque variation.

Unless the data sheet says otherwise, manufacturers typically measure a motor's torque constant,  $K_t$ , in one of two ways: They run the motor (at a constant speed) as a generator and convert the measured value of the motor voltage,  $K_b$ , to  $K_t$ ; or they determine  $K_t$  at the peak torque point under stall conditions. Because of the way manufacturers characterize the torque constants, you may find that motor data sheets don't always indicate the torque characteristics fully.

The bottom line is quite simple—multiplying the motor's  $K_t$  by motor current may not yield output torque for all rotor positions. Commutating a motor with a 6-step, or square-wave, drive typically can generate a torque ripple of 7.2%. Often, brushless dc motors are designed so that the back-EMF wave shapes are trapezoidal—that is, the wave shape during commutation is flat. A flat wave shape indicates a motor whose

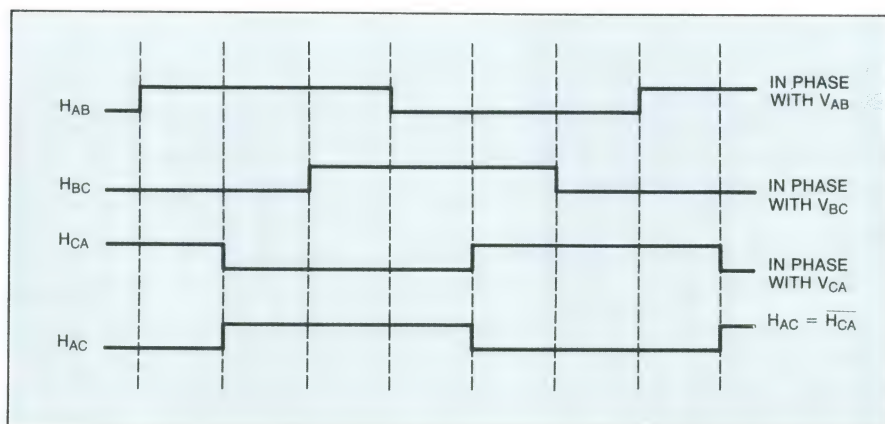


**Fig 2—Although sensor transitions in this figure correspond to the zero crossings of the waveforms in **Fig 1**, other relationships are possible. To implement a proper commutation scheme, you must know which relationship your motor manufacturer supplies.**



torque is constant (for a constant-current input) over one revolution.

You can also use pulse-width modulation (PWM) to control how much voltage you apply to the motor. Assume, for example, that the motor is stalled in sector 1 and transistors  $Q_A^+$  and  $Q_B^-$  are on (Fig 3). This condition connects the supply voltage to phases A and B, driving current from phase A to phase B. If you pulse either transistor off and on, you'll interrupt the current flow from the power supply.

Pulsing the transistors at a constant frequency while varying the on/off ratio modifies the applied voltage at the rate of the duty cycle. For example, if a constant-frequency logic signal that has a 50% duty cycle goes to the proper transistors (according to the commutation rules), the motor will rotate. However, the motor will not rotate as fast as it would using position-decoding alone.

The selection of a PWM frequency for an amplifier usually involves a tradeoff: The PWM frequency should be as high as is possible in order to limit current ripple. To reduce motor overheating, the form factor (ie, the ratio of average motor current plus rms ripple divided by average current) should be as close to 1.0 as possible. PWM techniques always involve some heating,

so the rms component of motor current causes heating of the motor even if the average motor current is zero. You can determine the current ripple for a given system at the time of stalling by using the following equation:  $dI = (E \times dt)/L$ , where  $E$  is the power supply voltage,  $dt$  is the duty cycle On time, and  $L$  is the motor's inductance.

### Watch for transistor-switch power losses

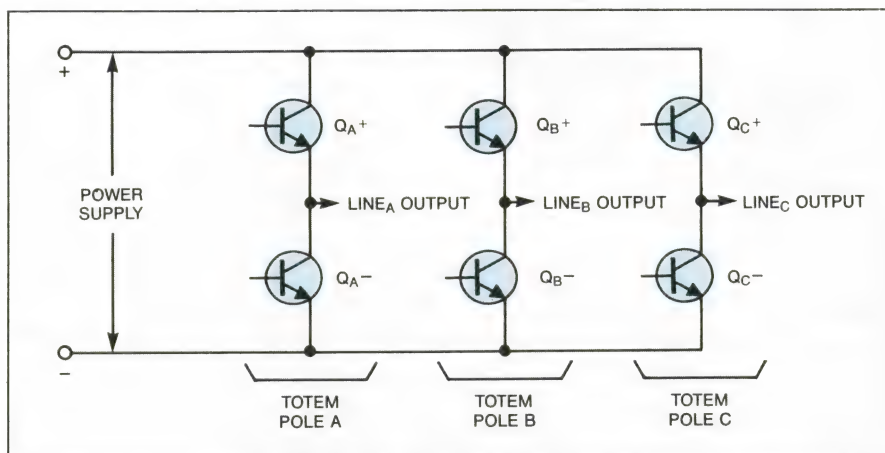
At some point, transistor-switch power losses limit how high the PWM frequency can be. The trend today is to switch at frequencies above the audible range, although some applications still switch in the 5- to 10-kHz range. Alternatively, you might want to consider PWM as a form of sampling. From this vantage point, in order to accurately control motor current, the PWM frequency (sampling rate) has to be high enough to provide the desired current-loop bandwidth. And in selecting a PWM frequency, you must still take the system voltage, the motor's inductance, and the motor's commutation into account.

There are other methods for changing a motor's speed. You might, for example, use a voltage regulator to adjust the supply voltage. PWM, however, has one significant advantage—it uses the commutation tran-

| $H_{AB} / H_{BC} / H_{CA}$ |          | 101 = 5 <sub>H</sub> | 100 = 4 <sub>H</sub> | 110 = 6 <sub>H</sub> | 010 = 2 <sub>H</sub> | 011 = 3 <sub>H</sub> | 001 = 1 <sub>H</sub> | 101 = 5 <sub>H</sub> |
|----------------------------|----------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|
| POSITION SECTOR            |          | 6                    | 1                    | 2                    | 3                    | 4                    | 5                    | 6                    |
| EXCITATION TABLE           | $\phi_A$ |                      | A+                   | A+                   |                      | A-                   | A-                   |                      |
|                            | $\phi_B$ | B-                   | B-                   |                      | B+                   | B+                   |                      | B-                   |
|                            | $\phi_C$ | C+                   |                      | C-                   | C-                   |                      | C+                   | C+                   |

**Fig 3—By logically combining the sensor outputs shown in Fig 2, you can develop 6 separate position sectors. This sector (or state) numbering system is specific to Inland Motor.**

**Fig 4—This totem-pole configuration takes advantage of both the positive and negative portions of the back-EMF waveform.**





*The 6-step commutation scheme takes advantage of both the positive and negative portions of the back-EMF waveform.*

sistors as switches rather than linear elements, thus reducing device heat dissipation. And since you need the transistors anyway, it's better to use them as controlled, high-frequency switches.

A general rule of thumb for ensuring that the amplifier can accurately control the motor current is to require that the motor inductance be at least 20  $\mu$ H for every volt of the system's power supply. In other words, for a 100V dc power-supply bus, the motor should have a minimum inductance of 2 mH.

### Sinusoidal commutation has its benefits

With sinusoidal commutation schemes, torque ripple over a complete revolution of the motor is nearly zero. If you design the drive electronics to provide sinusoidal current excitation and then apply this excitation to all three phases on a continuous basis, you can compensate for the motor's characteristic torque ripple.

## Drive-system basics

The current-mode or current-loop configuration is probably the most common form of brushless dc motor amplifier. This type of amplifier uses PWM techniques to control motor current and thereby control motor-torque output. By making the PWM duty cycle a function of the difference between actual and desired motor current, you can use motor torque to close the amplifier feedback loop. You must, of course, introduce some form of sensing device to monitor motor current.

One very logical technique for sensing motor current is quite basic: You can monitor the current in each motor phase. Note, however, that the sum of the motor-phase currents is zero. If the commutation process has phases A and B active, the current entering phase A is equal to the current leaving phase B. As a result, you can't simply add the motor currents together to determine torque. Rather, you have to monitor the sensor that's appropriate for the given rotor position.

When it comes to monitoring motor-lead current, you can use either two or three sensors because any one phase current is equal to minus the sum of the other two phase currents. For example,  $I_C = -(I_A + I_B)$ . You can use either magnetic or resistive elements to sense the lead current.

For a motor with sinusoidal back-EMF waveforms, you can express torque as:

$$T_O = T_1 + T_2 + T_3 \quad (1)$$

where

$$\begin{aligned} T_1 &= I_A K_t \sin \theta, \\ T_2 &= I_B K_t \sin (\theta - 120^\circ), \text{ and} \\ T_3 &= I_C K_t \sin (\theta - 240^\circ). \end{aligned}$$

$I_A$ ,  $I_B$ , and  $I_C$  are the motor phase currents;  $K_t$  is the motor torque constant.

If you modulate the motor-phase currents to produce the desired sinusoidal wave shape, then:

$$\begin{aligned} I_A &= I_{\sin} \theta, \\ I_B &= I_{\sin} (\theta - 120^\circ), \text{ and} \\ I_C &= I_{\sin} (\theta - 240^\circ). \end{aligned}$$

Substituting these values into **Eq 1** yields:

$$\begin{aligned} T_O &= K_t [\sin^2 \theta + \sin^2 (\theta - 120^\circ) + \sin^2 (\theta - 240^\circ)] \\ &= 1.5 I K_t. \end{aligned}$$

Thus, the torque output is independent of rotor position. Note that for a wye-wound motor, the current waveform is 30° out of phase with the motor terminal waveforms and in phase with the motor terminal-to-neutral waveform.

### Regeneration can cause problems

Regardless of which commutation scheme you use, you must address the regeneration problem. During motor braking and reversal, energy stored in the rotating motor and system returns to the amplifier's power supply. If the primary source of power is a battery or a motor generator, the regenerative current simply flows back into the supply.

Often, however, the source simply cannot accept the regeneration current. In such cases, the current pumps up the supply's nominal value to a level that's dependent on the inertia of the system—both motor-rotor inertia and load inertia. If only a small amount of energy is stored, the supply increase will be small, and the power-supply filter capacitors may be able to absorb the energy so that it has no effect on the drive amplifier. If the stored-energy level is high, you must clamp the supply voltage to a safe level. To do so, select load resistors that can dissipate the stored en-



ergy as heat. When you're selecting an amplifier during the system design phase, it's important to take this regeneration-related voltage rise into consideration.

### Don't forget phase advance

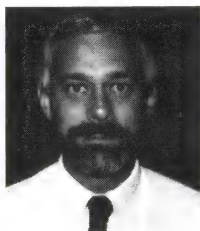
The commutation points shown in **Fig 1** are centered on either side of the back-EMF waveform. If the system voltage is 100V dc, then the voltage available for creating motor current equals 100V dc minus the back-EMF voltage. For the quasi-sinusoidal wave shape shown in **Fig 1**, you can see that the supply and back-EMF voltage difference is not a constant—it varies as a function of the wave shape. By adjusting the commutation points so that the motor commutates earlier on the back-EMF waveform, you can increase the average voltage difference between the supply voltage and the back-EMF voltage, and the motor will run faster.

This adjustment of commutation points is similar to rotating the position of the brushes relative to the permanent magnetic field in a brush-type motor. However, this technique discussed here is direction dependent; commutating early in one direction causes late commutation in the other direction. Tests show that controlled phase advance can provide extended motor performance for both 6-step and sine-wave amplifiers.

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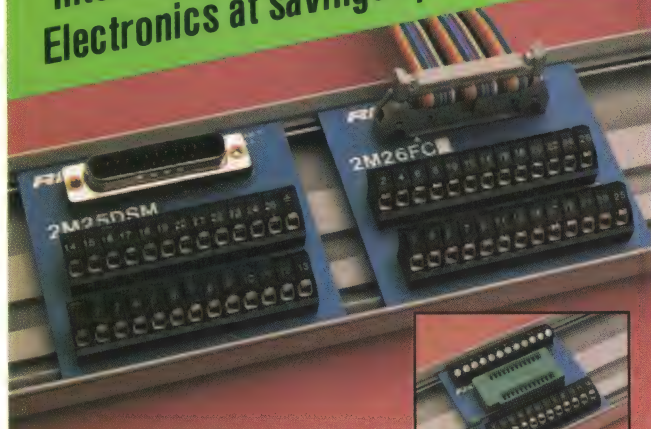
### Author's biography

*Malcolm B McCormick is an engineering manager at Inland Motor (Radford, VA). He has worked for Inland for eight years. At present, he's responsible for all electronic design and development activities. Malcolm holds a BSEE degree from Louisiana State Univ and an MSEE from Ohio State Univ. He is a member of IEEE and a registered professional engineer. In his spare time, Malcolm enjoys jogging, hiking, music, and photography.*



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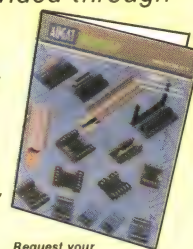
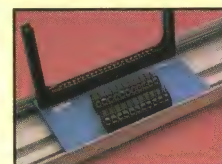
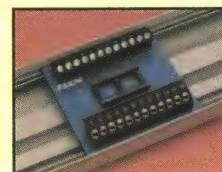
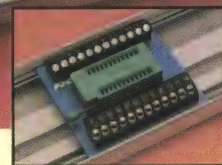
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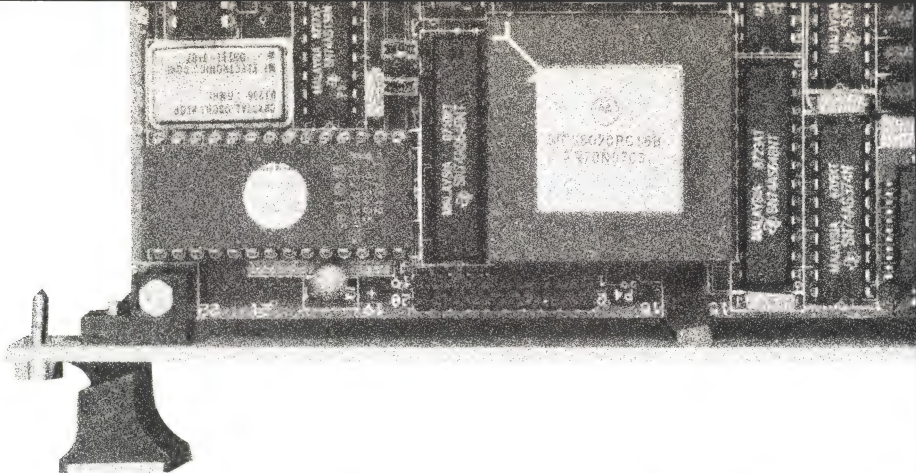
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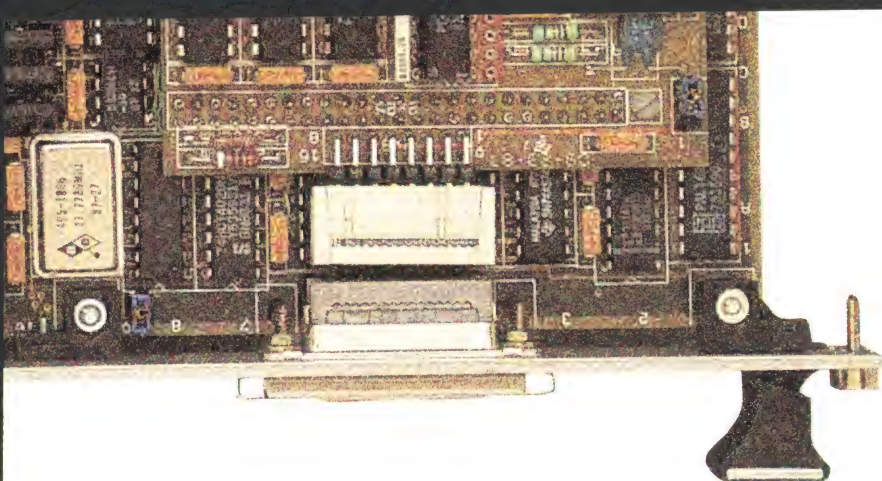
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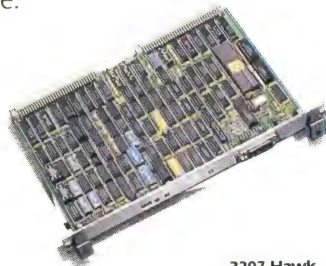
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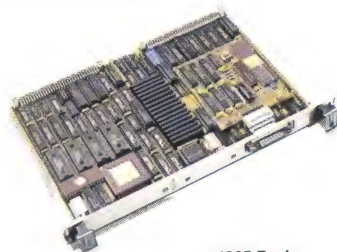
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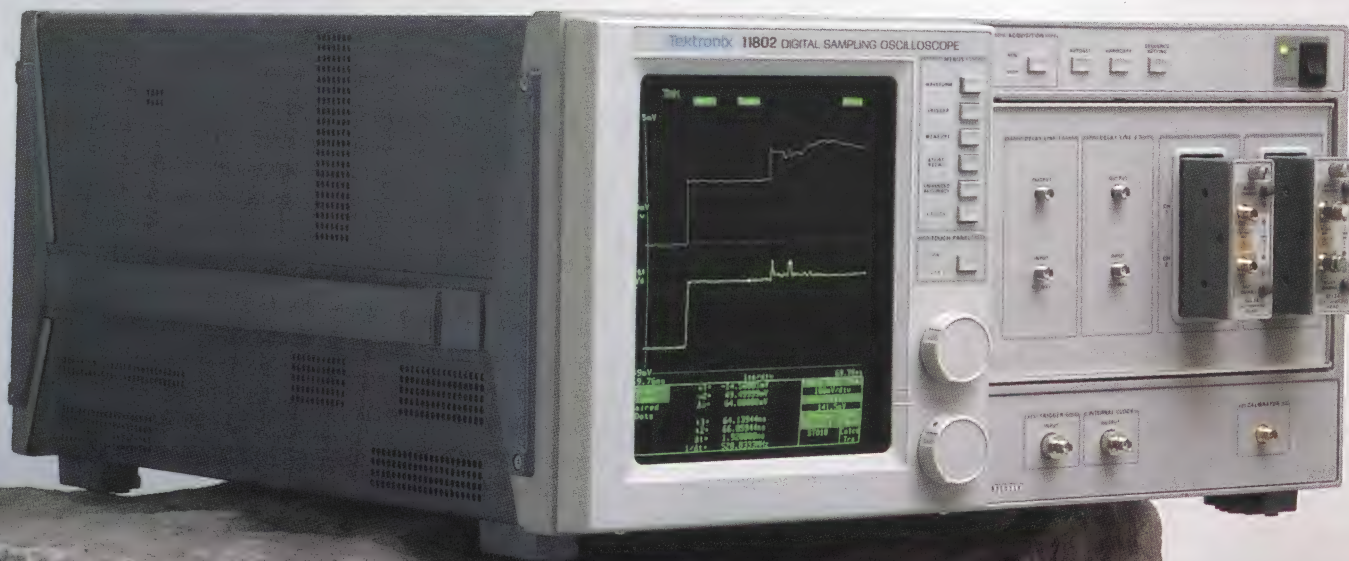
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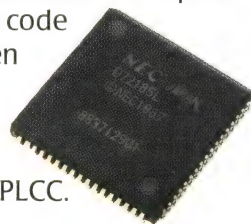
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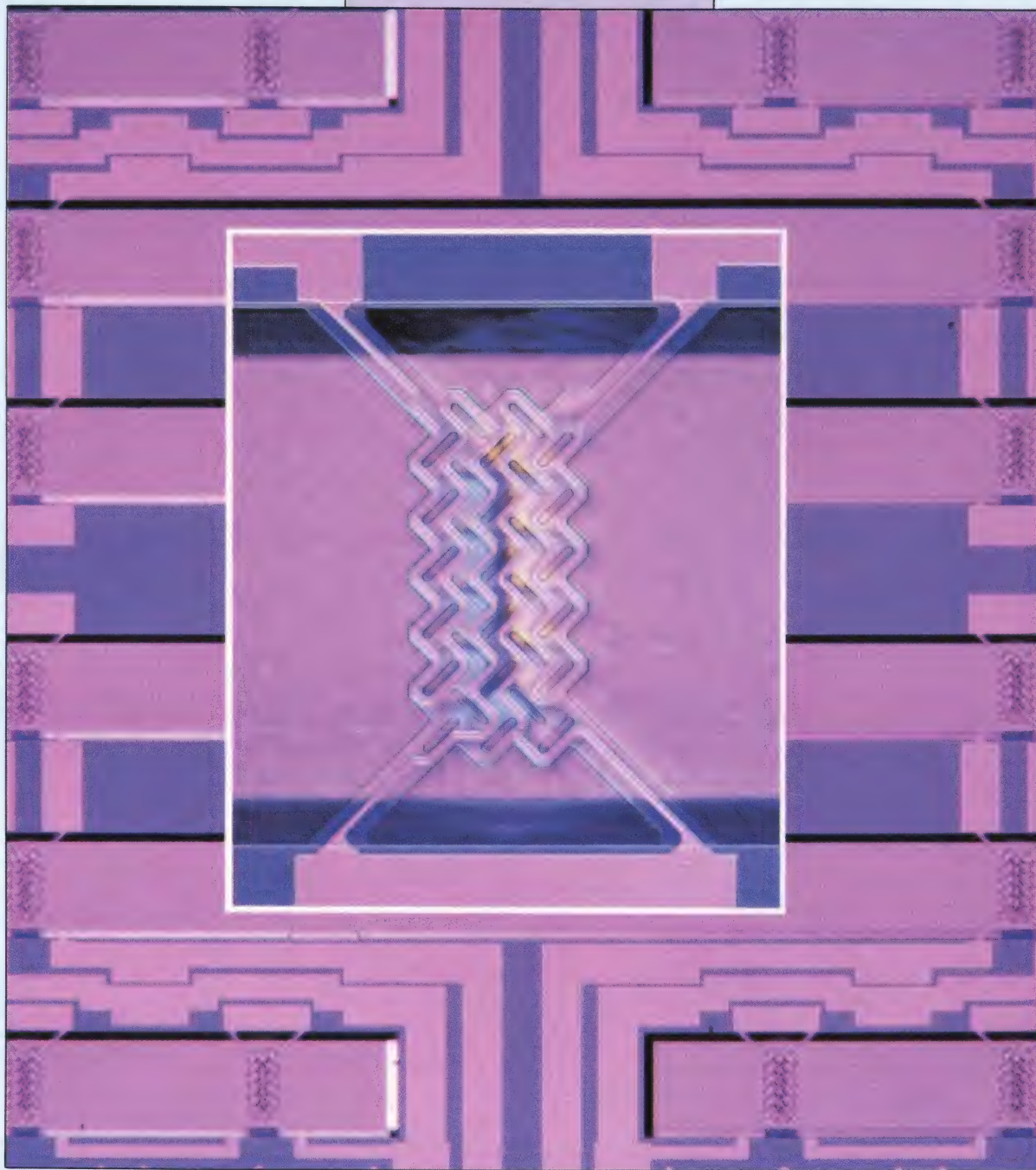


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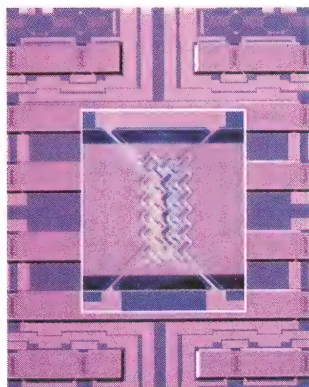
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### Amplifiers

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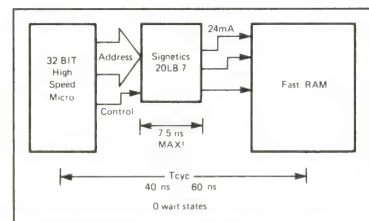
Update: Searching for the optimal PLD. *Lewis, Sasha, Northwestern*



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Fast, full-featured 4-Mbit DRAM controllers begin to surface. Martin, S Louis, Contributing Editor; *Computer Design*, 08/01/88, pg 26, 2 pgs.  
Smart memories beat bottleneck blues. Morton, Steven G, Oxford Computer; *ESD*, 07/88, pg 70, 3.5 pgs.

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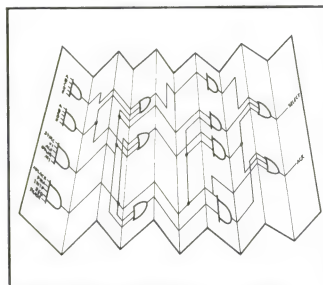
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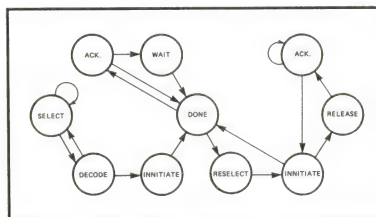
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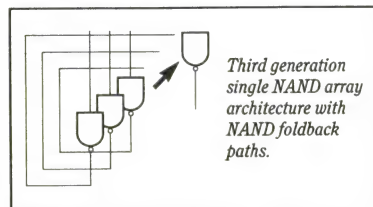
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## T

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## EDITED BY CHARLES H SMALL

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Bowling Green State University,  
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If you use a loop voltage greater than 24V, you must place a 750 $\Omega$ , 1/2W resistor in series with the external output transistor. In no case can the loop voltage exceed 40V dc. The load resistor, R<sub>L</sub>, can be any value as long as the voltage between pin 7 and pin 8 is between 11.6 and 24V dc.

To calibrate the simulator, first insert an ammeter into the loop and adjust the simulator's output-current pot,  $R_1$ , to minimum resistance. Next, adjust the input-offset pot,  $R_3$ , until the meter displays 4 mA. Then adjust pot  $R_1$  to maximum resistance and adjust the span pot,  $R_5$ , until the meter reads 20 mA. **EDN**

The circuit diagram shows a precision current source using the XTR101 IC. The IC is configured with a feedback resistor  $R_3$  (100k) and a resistor  $R_4$  (1M) connected to the NULL pin. The output is adjusted using a potentiometer  $R_1$  (100) and a resistor  $R_2$  (2.49k) with a 0.01  $\mu$ F capacitor. The output current is 1 mA. The circuit is powered by a 24V dc LOOP SUPPLY and a 1N4004 diode. A note indicates that if the loop supply is between 26 and 40V dc, a 750  $\Omega$  1/2W resistor should be inserted.

**Fig 1—With the aid of this 4- to 20-mA simulator, you can test current-loop devices.**



## Switcher boosts regulator's efficiency

Brian Huffman  
*Linear Technology Corp, Milpitas, CA*

Placing a linear regulator in the servo loop of a switching regulator yields a circuit that has both the precise regulation of a linear regulator and the efficiency of a switcher. The circuit in **Fig 1** maintains only the bare minimum voltage necessary for proper operation across the linear regulator, even if you short the outputs. (Note that **Fig 1** shows a pair of identical supplies configured as a bipolar supply.)

The voltage drop across the resistive divider, which bridges the 2.5V, LT1004 voltage reference, determines the differential voltage across the linear regulator. When the comparator senses that the regulator's

input voltage is below the differential-voltage setting, the comparator switches low, thus turning on  $Q_1$ . With  $Q_1$  on, charge stored on  $C_1$  flows through  $Q_1$ , charges up the inductor and  $C_2$ , and supplies the load via the linear regulator.

When the linear regulator's input voltage rises above the differential-voltage setting, the comparator's output goes high, thus turning off  $Q_1$ . With  $Q_1$  off, the stored energy in  $C_2$  and the inductor supply the load.  $R_1$  and  $R_2$  set the switching loop's hysteresis. Protection diodes  $D_1$  and  $D_2$  eliminate common-load problems.

EDN

**To Vote For This Design, Circle No 749**

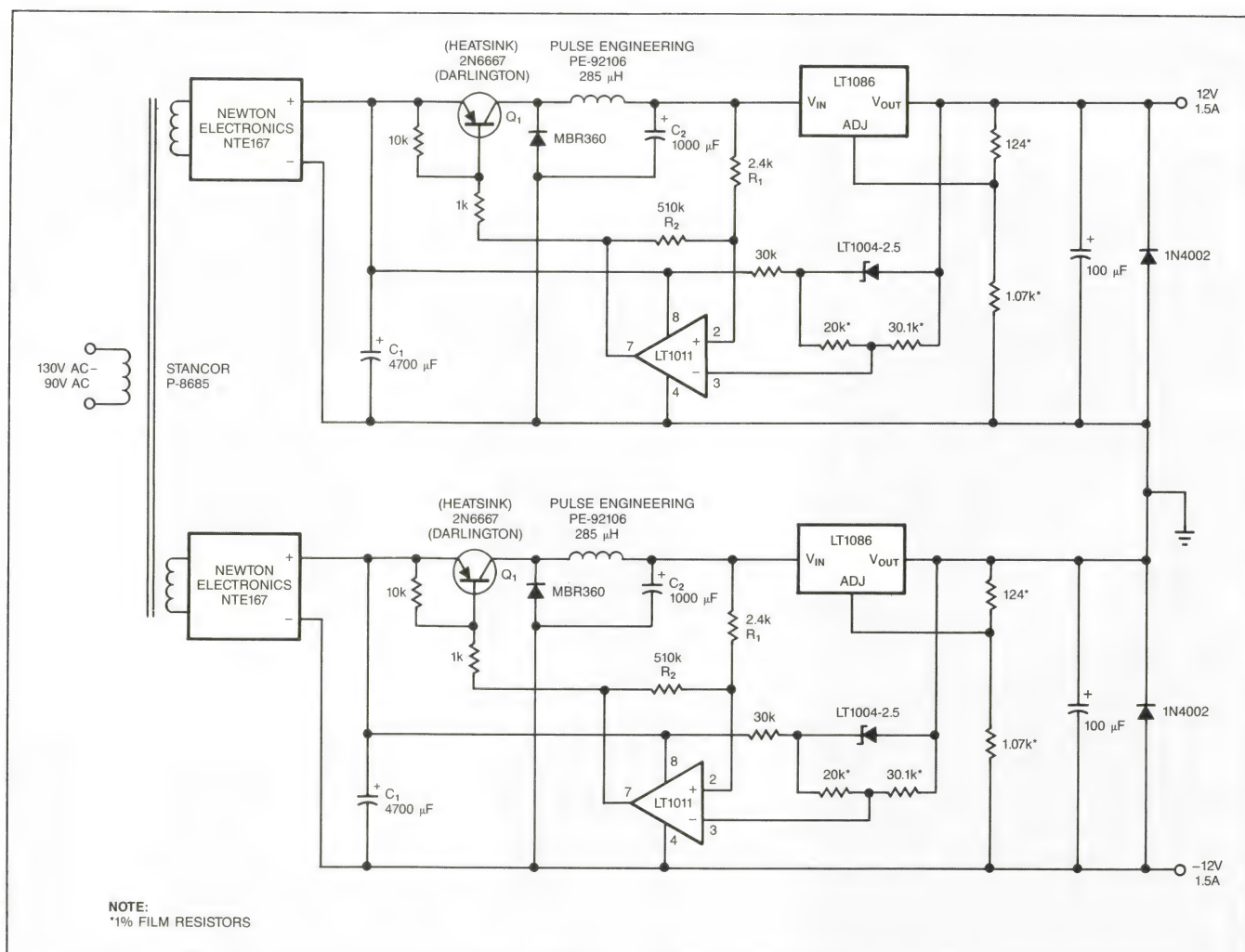
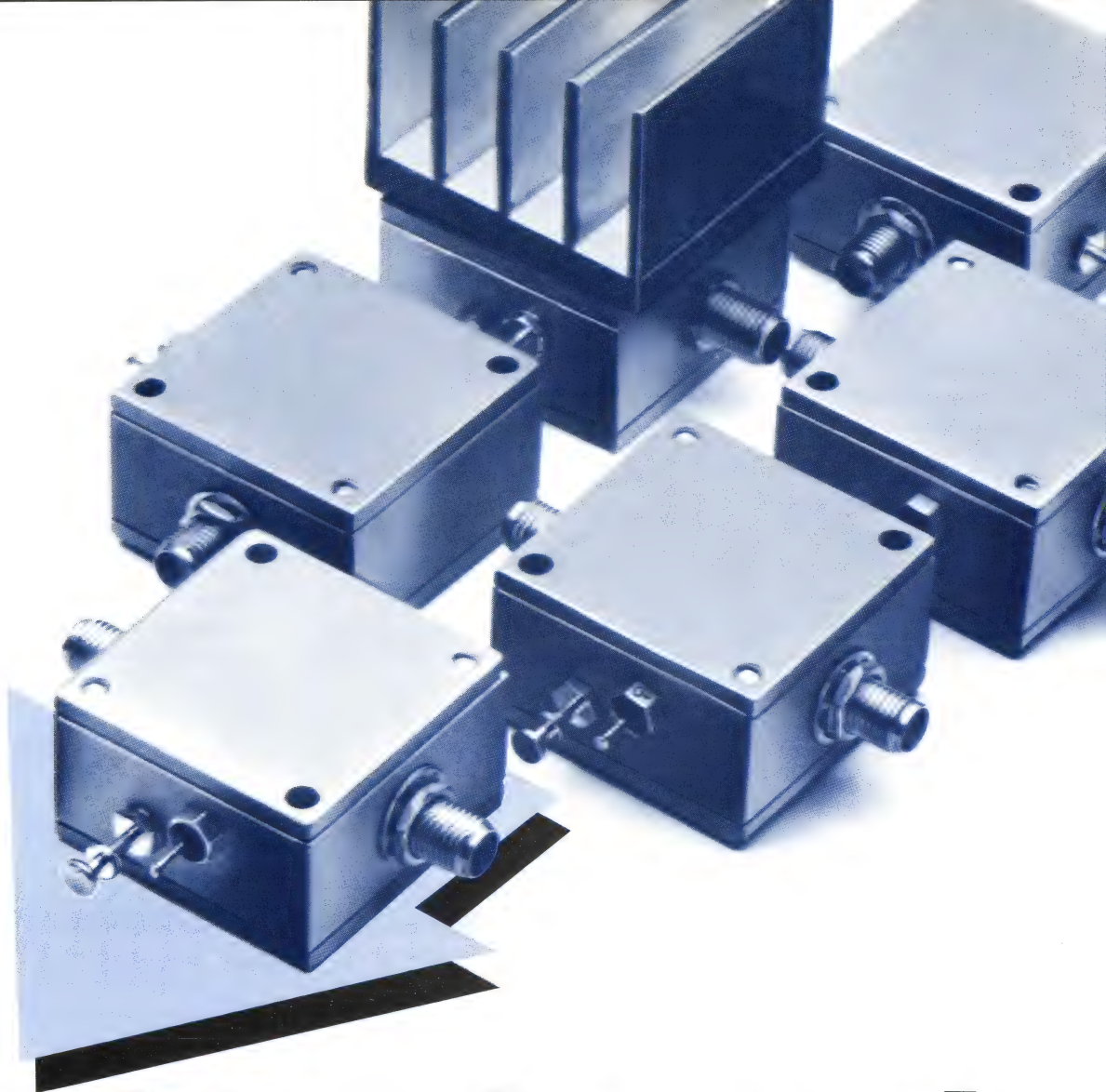


**Fig 1—Placing a 3-terminal linear regulator within the servo loop of a switching regulator yields a power supply with tight regulation and good efficiency.**





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|------------|------------------|--------------------|----------------------------------|---------------|-------------------------------|
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| ZFL-500LN  | 0.1-500          | 24                 | +5                               | 2.9           | 79.95                         |
| ZFL-750    | 0.2-750          | 18                 | +9                               | 6.0           | 74.95                         |
| ZFL-1000   | 0.1-1000         | 17                 | +9                               | 6.0           | 79.95                         |
| ZFL-1000G* | 10-1000          | 17                 | +3                               | 12.0          | 199.00                        |
| ZFL-1000H  | 10-1000          | 28                 | +20                              | 5.0           | 219.00                        |
| ZFL-500HLN | 10-50            | 19                 | +16                              | 3.8           | 99.95                         |
| ZFL-1000LN | 0.1-1000         | 20                 | +3                               | 2.9           | 89.95                         |
| ZFL-1000VH | 10-1000          | 20                 | +25                              | 4.5           | 229.00                        |
| ZFL-2000   | 10-2000          | 20                 | +17**                            | 7.0           | 219.00                        |

\* 30dB gain control

\*\*+15dBm below 1000MHz

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## Filter settles faster than a Butterworth

Einar Abell

ADA Instruments, Three Rivers, CA

The filter circuit shown in **Fig 1** settles in half the time that a Butterworth filter requires but without losing any of its ability to attenuate signals in its stopband. Unlike the Butterworth filter, which is optimized for frequency-domain response, this circuit is optimized for time-domain response. And although it has a simple design, the circuit provides much the same overall performance as a Bessel filter. As an added bonus, the filter circuit uses standard capacitor values.

The circuit comprises two cascaded, Sallen-Key, low-pass filters with damping factors of 0.674 and 1.00, respectively. For good performance, the circuit requires close-tolerance capacitors rated at 1 or 2%. Overshoot in response to a step input is about 0.5%; you can reduce the overshoot to under 0.1% by adjusting  $R_1$ .

The component values in **Fig 1** yield a 100-Hz corner frequency. You can use the following equations to adapt the circuit to other requirements:

$$\begin{aligned} C_1 &= 2.2C_2 \\ C_3 &= C_4 \\ R_1 &= R_2, R_3 = R_4 \\ f_c &= \frac{1}{2\pi R_1 \sqrt{C_1 C_2}} = \frac{1}{2\pi R_3 C_3} \end{aligned}$$

If  $C_3 = C_4 = \sqrt{C_1 C_2}$ ,  
then  $R_1 = R_2 = R_3 = R_4$ ,  
and  $f_c = \frac{1}{2\pi R_1 C_3}$ .

The center frequency is represented by  $f_c$ .

EDN

To Vote For This Design, Circle No 746

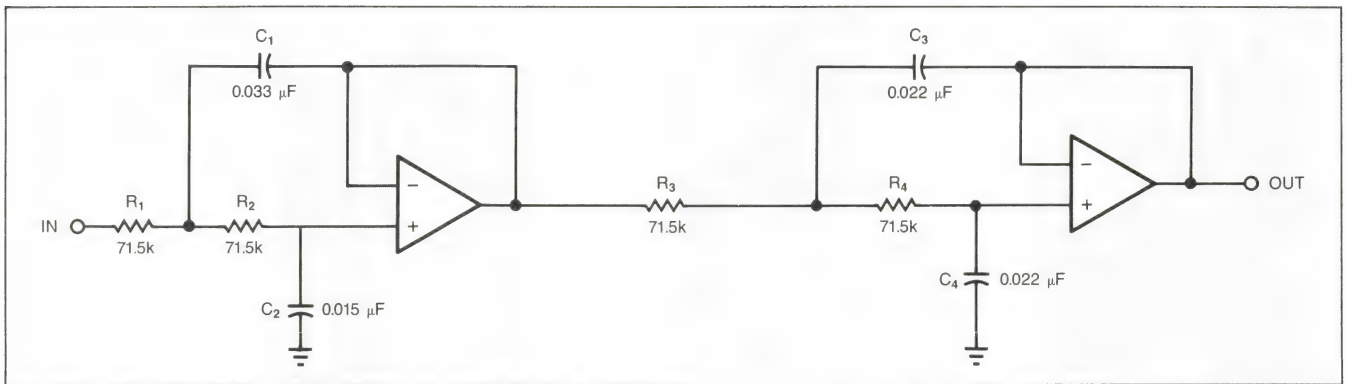


**Fig 1**—This 100-Hz, 2-stage, Sallen-Key, lowpass filter has better time-domain response than a Butterworth filter.

## Reactive CCD drive saves power

Michael A Wyatt

Honeywell SSAvD, Clearwater, FL

Charge-coupled devices (CCDs), such as those used in filters and convolvers, have large capacitances associated with their clock inputs. A reactive clock drive can resonate with this CCD capacitance to reduce the power necessary to drive these clock inputs by as much

as 90%.

**Fig 1** illustrates a reactive CCD clock-drive circuit where  $C_L$  is the effective CCD clock-drive capacitance. MOSFETs  $Q_1$  and  $Q_2$  form a bilateral MOS switch, and  $Q_3$  and  $Q_4$  serve as unilateral switches. At time  $t_0$ , switches  $Q_3$  and  $Q_4$  are open and bilateral switch  $Q_{1,2}$  is closed. Current begins to flow into  $C_L$  through the circuit's series resistance,  $R_S$ , and  $L$ . The following



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Digital ECL/TTL  
200 MHz Clock

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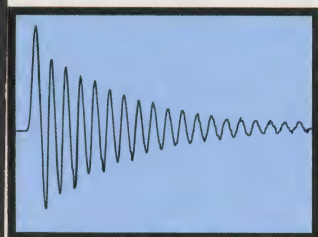
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Low Cost, Upgradeable

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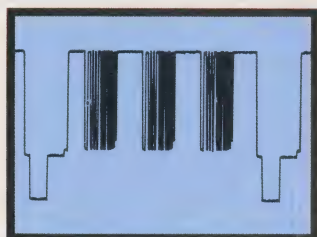
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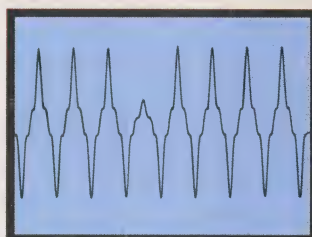
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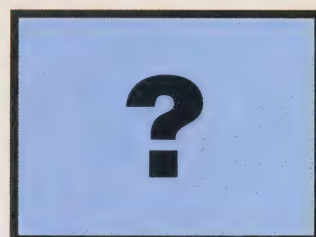
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Your Signal



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Circle 100 for Information

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# DESIGN IDEAS

equation describes the voltage across  $C_L$ :

$$V_{CL}(t) = \frac{V_S}{2 \left( 1 - \frac{1}{Be^{-Zw_0t}} \right) (\sin(w_0Bt + I))} \quad (1)$$

where  $w_0 = \sqrt{\frac{1}{LC_L}}$ ,

$$Z = \frac{R_S}{2Lw_0},$$

$$B = \sqrt{1 - Z^2},$$

$$I = \arctan\left(\frac{B}{Z}\right).$$

$V_{CL}$  reaches a maximum at

$$t = \frac{\pi}{w_0B}.$$

For a high-Q circuit where  $R_S$  is negligibly small, this maximum is almost equal to  $V_S$ . At time  $t_1$ ,  $Q_{1,2}$  opens and  $Q_3$  closes, thus holding  $V_{CL}$  at  $V_S$ .  $Q_3$  also refreshes any energy lost in  $R_S$  by pulling  $V_{CL}$  to  $V_S$ . Subsequently,  $Q_3$  remains closed until time  $t_2$  when  $Q_3$  opens and  $Q_{1,2}$  closes. This action causes  $V_{CL}$  to ring toward zero volts. When  $\pi/\omega_0B$  seconds elapse after  $t_2$ ,  $V_{CL}$  reaches a minimum of near zero volts. At time  $t_3$ ,  $Q_{1,2}$  opens and  $Q_4$  closes bringing  $V_{CL}$  to ground.  $V_{CL}$  is then clamped at ground until the drive cycle begins again.

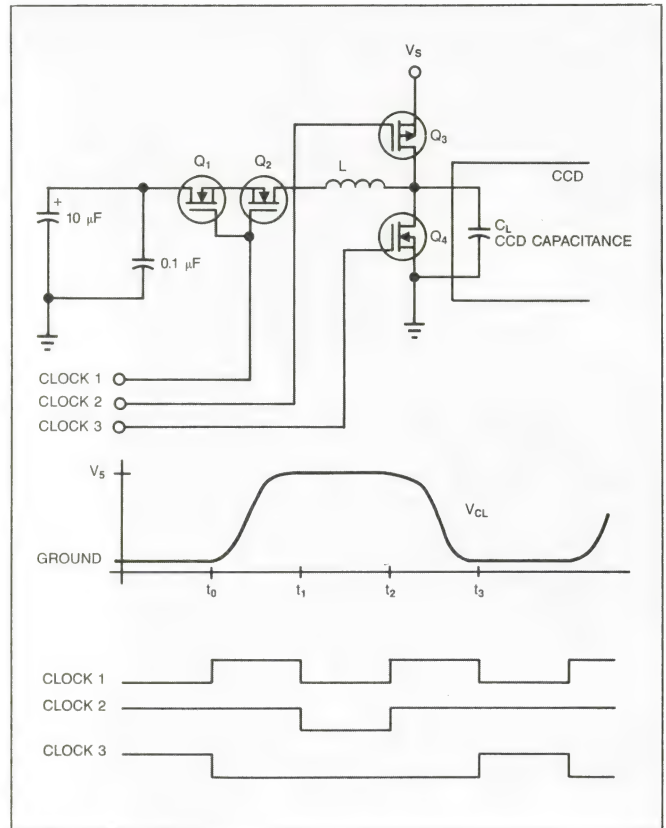


**Fig 1—The MOSFET switches and inductor  $L$  form a reactive clock-drive circuit with the inherent large capacitance of a charge-coupled device's clock inputs. This circuit consumes 90% less power than a conventional clock-drive circuit.**

## LISTING 1—REACTIVE CLOCK-DRIVE PROGRAMS

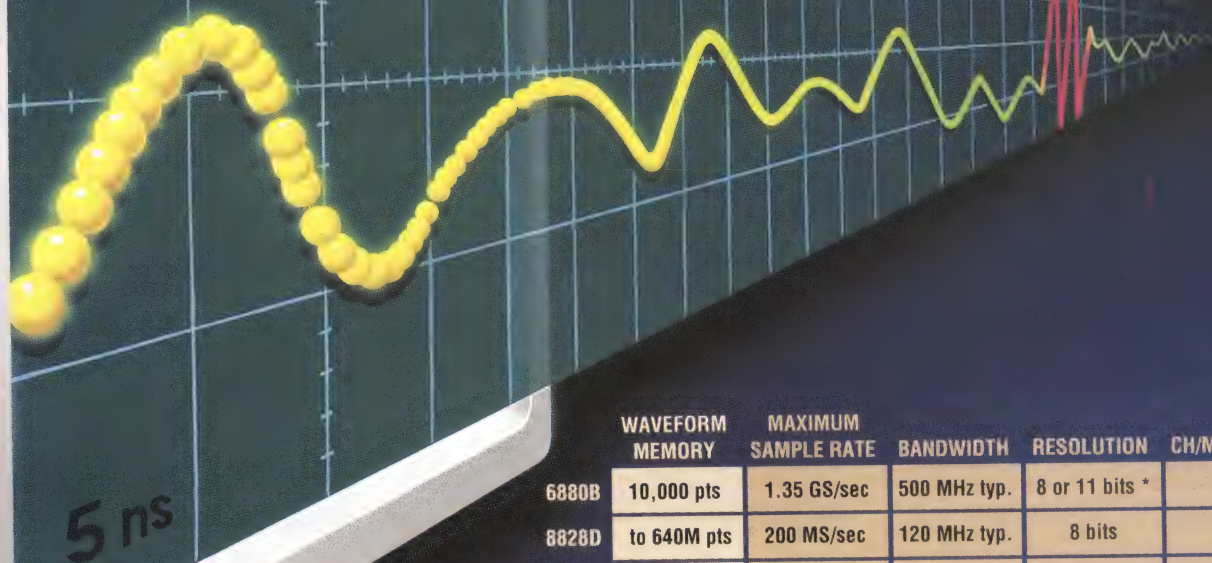
### RCLK

|                  |               |            |                  |                     |
|------------------|---------------|------------|------------------|---------------------|
| 01 *LBL "RCLK"   | 27 "ENTER QL" | 53 ENG 3   | 79 *             | 105 "WITH DRIVE"    |
| 02 "REVA 1.83"   | 28 PROMPT     | 54 "CL="   | 80 2             | 106 PRA             |
| 03 RAD           | 29 STO 24     | 55 ARCL 21 | 81 /             | 107 CF 13           |
| 04 "CK PLOT"     | 30 BEEP       | 56 PRA     | 82 STO 28        | 108 "PC="           |
| 05 CF 13         | 31 "ENTER VS" | 57 "F="    | 83 PI            | 109 ARCL X          |
| 06 ENG 3         | 32 PROMPT     | 58 ARCL 22 | 84 *             | 110 PRA             |
| 07 SF 12         | 33 STO 25     | 59 PRA     | 85 CHS           | 111 SF 13           |
| 08 " REACTIVE"   | 34 BEEP       | 60 FIX 2   | 86 E1X           | 112 "WITHOUT DRIVE" |
| 09 PRA           | 35 RCL 22     | 61 "RS="   | 87 CHS           | 113 PRA             |
| 10 "CLOCK DRIVE" | 36 PI         | 62 ARCL 23 | 88 1             | 114 CF 13           |
| 11 PRA           | 37 *          | 63 PRA     | 89 +             | 115 RCL 25          |
| 12 CF 12         | 38 4          | 64 "VS="   | 90 RCL 22        | 116 X12             |
| 13 ADV           | 39 *          | 65 ARCL 25 | 91 *             | 117 RCL 21          |
| 14 BEEP          | 40 STO 26     | 66 PRA     | 92 RCL 25        | 118 *               |
| 15 "ENTER CL"    | 41 X12        | 67 ENG 3   | 93 2             | 119 RCL 22          |
| 16 PROMPT        | 42 RCL 21     | 68 RCL 21  | 94 /             | 120 *               |
| 17 STO 21        | 43 *          | 69 RCL 27  | 95 X12           | 121 "PL="           |
| 18 BEEP          | 44 1/X        | 70 /       | 96 *             | 122 ARCL X          |
| 19 "ENTER F"     | 45 STO 27     | 71 SOFT    | 97 RCL 21        | 123 PRA             |
| 20 PROMPT        | 46 "L="       | 72 RCL 23  | 98 *             | 124 ADV             |
| 21 STO 22        | 47 ARCL X     | 73 RCL 26  | 99 4             | 125 RCL 28          |
| 22 BEEP          | 48 PRA        | 74 RCL 27  | 100 *            | 126 X12             |
| 23 "ENTER RS"    | 49 FIX 2      | 75 *       | 101 ADV          | 127 CHS             |
| 24 PROMPT        | 50 "QL="      | 76 RCL 24  | 102 "POWER LOSS" | 128 1               |
| 25 STO 23        | 51 ARCL 24    | 77 /       | 103 PRA          | 129 +               |
| 26 BEEP          | 52 PRA        | 78 +       | 104 SF 13        | 130 SORT            |

continued on pg 210



# Capturing the ENTIRE Waveform?



|       | WAVEFORM<br>MEMORY | MAXIMUM<br>SAMPLE RATE | BANDWIDTH    | RESOLUTION     | CH/MODULE |
|-------|--------------------|------------------------|--------------|----------------|-----------|
| 6880B | 10,000 pts         | 1.35 GS/sec            | 500 MHz typ. | 8 or 11 bits * | 1         |
| 8828D | to 640M pts        | 200 MS/sec             | 120 MHz typ. | 8 bits         | 1         |
| 8818A | to 640M pts        | 100 MS/sec             | 120 MHz typ. | 8 bits         | 1         |
| 6810  | to 8M pts          | 5 MS/sec               | 2.5 MHz      | 12 bits        | 4/2/1     |
| 8212A | to 384k pts        | 40 kS/sec              | 50 kHz       | 12 bits        | 32/16/8/4 |

\* at reduced bandwidth

IEEE 488

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# DESIGN IDEAS

## LISTING 1—REACTIVE CLOCK-DRIVE PROGRAMS (Continued)

### RCLK

|            |                   |                |                |                                                                                                                                                                                                                                                                                                                                                                    |
|------------|-------------------|----------------|----------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 131 STO 29 | 173 "RCLOCK"      | 215 RCL 26     | 18 RCL 32      | PLOT OF RCLOCK<br>X <UNITS= 1.> ↓<br>Y <UNITS= 1.> +<br>0.0 15.0<br>0.0<br> ----- <br>0.00<br>0.15<br>0.30<br>0.45<br>0.60<br>0.75<br>0.90<br>1.05<br>1.20<br>1.35<br>1.50<br>1.65<br>1.80<br>1.95<br>2.10<br>2.25<br>2.40<br>2.55<br>2.70<br>2.85<br>3.00<br>3.15<br>3.30<br>3.45<br>3.60<br>3.75<br>3.90<br>4.05<br>4.20<br>4.35<br>4.50<br>4.65<br>4.80<br>4.95 |
| 132 PI     | 174 ASTO 11       | 216 *          | 19 *           |                                                                                                                                                                                                                                                                                                                                                                    |
| 133 RCL 26 | 175 ENG 3         | 217 RCL 31     | 20 CHS         |                                                                                                                                                                                                                                                                                                                                                                    |
| 134 /      | 176 XROM "PRPLOT" | 218 +          | 21 E1X         |                                                                                                                                                                                                                                                                                                                                                                    |
| 135 RCL 29 | 177 ADV           | 219 SIN        | 22 *           |                                                                                                                                                                                                                                                                                                                                                                    |
| 136 /      | 178 RCL 35        | 220 RCL 28     | 23 RCL 29      |                                                                                                                                                                                                                                                                                                                                                                    |
| 137 STO 30 | 179 1/X           | 221 RCL 26     | 24 /           |                                                                                                                                                                                                                                                                                                                                                                    |
| 138 RCL 29 | 180 "TIME INC="   | 222 *          | 25 1           |                                                                                                                                                                                                                                                                                                                                                                    |
| 139 RCL 23 | 181 ARCL X        | 223 RCL 32     | 26 +           |                                                                                                                                                                                                                                                                                                                                                                    |
| 140 /      | 182 PRA           | 224 *          | 27 RCL 25      |                                                                                                                                                                                                                                                                                                                                                                    |
| 141 ATAN   | 183 ADV           | 225 CHS        | 28 *           |                                                                                                                                                                                                                                                                                                                                                                    |
| 142 STO 31 | 184 ADV           | 226 E1X        | 29 2           |                                                                                                                                                                                                                                                                                                                                                                    |
| 143 0      | 185 *LBL "RCLOCK" | 227 *          | 30 /           |                                                                                                                                                                                                                                                                                                                                                                    |
| 144 STO 32 | 186 RCL 35        | 228 RCL 29     | 31 END         |                                                                                                                                                                                                                                                                                                                                                                    |
| 145 0      | 187 /             | 229 /          |                |                                                                                                                                                                                                                                                                                                                                                                    |
| 146 STO 00 | 188 STO 32        | 230 CHS        | 01 *LBL "ZERO" |                                                                                                                                                                                                                                                                                                                                                                    |
| 147 RCL 25 | 189 RCL 22        | 231 1          | 02 0           |                                                                                                                                                                                                                                                                                                                                                                    |
| 148 STO 01 | 190 1/X           | 232 +          | 03 END         |                                                                                                                                                                                                                                                                                                                                                                    |
| 149 0      | 191 3             | 233 RCL 25     |                |                                                                                                                                                                                                                                                                                                                                                                    |
| 150 STO 03 | 192 *             | 234 *          | 01 *LBL "Y"    |                                                                                                                                                                                                                                                                                                                                                                    |
| 151 STO 04 | 193 4             | 235 2          | 02 RCL 25      |                                                                                                                                                                                                                                                                                                                                                                    |
| 152 STO 08 | 194 /             | 236 /          | 03 END         |                                                                                                                                                                                                                                                                                                                                                                    |
| 153 RCL 22 | 195 RCL 32        | 237 END        |                |                                                                                                                                                                                                                                                                                                                                                                    |
| 154 1/X    | 196 XYY?          |                |                |                                                                                                                                                                                                                                                                                                                                                                    |
| 155 ENTER↑ | 197 GTO "ZERO"    | 01 *LBL "DOWN" |                |                                                                                                                                                                                                                                                                                                                                                                    |
| 156 LOG    | 198 RCL 22        | 02 RCL 32      |                |                                                                                                                                                                                                                                                                                                                                                                    |
| 157 CHS    | 199 1/X           | 03 RCL 30      |                |                                                                                                                                                                                                                                                                                                                                                                    |
| 158 INT    | 200 2             | 04 2           |                |                                                                                                                                                                                                                                                                                                                                                                    |
| 159 1      | 201 /             | 05 *           |                |                                                                                                                                                                                                                                                                                                                                                                    |
| 160 +      | 202 RCL 32        | 06 -           |                |                                                                                                                                                                                                                                                                                                                                                                    |
| 161 101X   | 203 XYY?          | 07 STO 32      |                |                                                                                                                                                                                                                                                                                                                                                                    |
| 162 STO 35 | 204 GTO "DOWN"    | 08 RCL 29      |                |                                                                                                                                                                                                                                                                                                                                                                    |
| 163 *      | 205 RCL 22        | 09 *           |                |                                                                                                                                                                                                                                                                                                                                                                    |
| 164 STO 09 | 206 1/X           | 10 RCL 26      |                |                                                                                                                                                                                                                                                                                                                                                                    |
| 165 .5     | 207 4             | 11 *           |                |                                                                                                                                                                                                                                                                                                                                                                    |
| 166 +      | 208 /             | 12 RCL 31      |                |                                                                                                                                                                                                                                                                                                                                                                    |
| 167 FIX 0  | 209 RCL 32        | 13 +           |                |                                                                                                                                                                                                                                                                                                                                                                    |
| 168 RND    | 210 XYY?          | 14 SIN         |                |                                                                                                                                                                                                                                                                                                                                                                    |
| 169 FIX 4  | 211 GTO "V"       | 15 RCL 28      |                |                                                                                                                                                                                                                                                                                                                                                                    |
| 170 40     | 212 RCL 32        | 16 RCL 26      |                |                                                                                                                                                                                                                                                                                                                                                                    |
| 171 /      | 213 RCL 29        | 17 *           |                |                                                                                                                                                                                                                                                                                                                                                                    |
| 172 STO 10 | 214 *             |                |                |                                                                                                                                                                                                                                                                                                                                                                    |

### REACTIVE CLOCK DRIVE

L=31.66E-6  
 QL=100.00  
 CL=5.000E-9  
 F=200.0E3  
 RS=4.00  
 VS=15.00

POWER LOSS  
 with drive  
 PC=20.32E-3  
 without drive  
 PL=225.0E-3

### PLATT

|                  |                  |            |            |           |
|------------------|------------------|------------|------------|-----------|
| 01 *LBL "PLATT"  | 21 STO 22        | 41 *       | 61 "F="    | 81 /      |
| 02 "REVA 1.03"   | 22 BEEP          | 42 4       | 62 ARCL 22 | 82 +      |
| 03 "PL PLOT"     | 23 "ENTER RS"    | 43 *       | 63 PRA     | 83 *      |
| 04 PRA           | 24 PROMPT        | 44 STO 26  | 64 FIX 2   | 84 2      |
| 05 CF 13         | 25 STO 23        | 45 X12     | 65 "RS="   | 85 /      |
| 06 ENG 3         | 26 BEEP          | 46 RCL 21  | 66 ARCL 23 | 86 STO 28 |
| 07 SF 12         | 27 "ENTER QL"    | 47 *       | 67 PRA     | 87 RCL 26 |
| 08 " REACTIVE"   | 28 PROMPT        | 48 1/X     | 68 "VS="   | 88 1/X    |
| 09 PRA           | 29 STO 24        | 49 STO 27  | 69 ARCL 25 | 89 PI     |
| 10 "CLOCK DRIVE" | 30 BEEP          | 50 "L="    | 70 PRA     | 90 *      |
| 11 PRA           | 31 "ENTER VS"    | 51 ARCL X  | 71 ENG 3   | 91 RCL 28 |
| 12 CF 12         | 32 PROMPT        | 52 PRA     | 72 RCL 21  | 92 X12    |
| 13 ADV           | 33 STO 25        | 53 FIX 2   | 73 RCL 27  | 93 CHS    |
| 14 BEEP          | 34 BEEP          | 54 "QL="   | 74 /       | 94 1      |
| 15 "ENTER CL"    | 35 "% DEVIATION" | 55 ARCL 24 | 75 SORT    | 95 +      |
| 16 PROMPT        | 36 PROMPT        | 56 PRA     | 76 RCL 23  | 96 SORT   |
| 17 STO 21        | 37 STO 19        | 57 ENG 3   | 77 RCL 26  | 97 /      |
| 18 BEEP          | 38 BEEP          | 58 "CL="   | 78 RCL 27  | 98 STO 30 |
| 19 "ENTER F"     | 39 RCL 22        | 59 ARCL 21 | 79 *       | 99 ENG 3  |
| 20 PROMPT        | 40 PI            | 60 PRA     | 80 RCL 24  |           |



# DESIGN IDEAS

## LISTING 1—REACTIVE CLOCK-DRIVE PROGRAMS (Continued)

### PLATT

```

100 "TO="
101 ARCL 30
102 PRA
103 FIX 2
104 "%D="
105 ARCL 19
106 PRA
107 RCL 19
108 100
109 /
110 CHS
111 1
112 +
113 RCL 30
114 *
115 RCL 26
116 *
117 ENTER↑
118 ENTER↑
119 COS
120 X<Y
121 RCL 28
122 CHS
123 *
124 E1X
125 *
126 1
127 +
128 RCL 25
129 X12
130 *
131 RCL 21
132 *
133 RCL 22
134 *
135 STO 01

136 RCL 19
137 100
138 /
139 1
140 +
141 RCL 30
142 *
143 RCL 26
144 *
145 ENTER↑
146 COS
147 X<Y
148 RCL 28
149 CHS
150 *
151 E1X
152 *
153 1
154 +
155 RCL 25
156 X12
157 *
158 RCL 21
159 *
160 RCL 22
161 *
162 RCL 01
163 X<Y
164 X12
165 STO 01
166 RCL 30
167 RCL 26
168 *
169 ENTER↑
170 COS
171 X<Y

172 RCL 28
173 CHS
174 *
175 E1X
176 *
177 1
178 +
179 RCL 25
180 X12
181 *
182 RCL 21
183 *
184 RCL 22
185 *
186 STO 00
187 STO 04
188 RCL 19
189 STO 09
190 CHS
191 STO 08
192 0
193 STO 03
194 20
195 CHS
196 STO 10
197 "PLTCL"
198 ASTO 11
199 XROM "PRPLOT"
200 ADV
201 ENG 3
202 "PMIN="
203 ARCL 00
204 PRA
205 "PMAX="
206 ARCL 01
207 PRA

208 ADV
209 ADV
210 LBL "PLTCL"
211 100
212 /
213 1
214 +
215 RCL 30
216 *
217 RCL 26
218 *
219 ENTER↑
220 COS
221 X<Y
222 RCL 28
223 CHS
224 *
225 E1X
226 *
227 1
228 +
229 RCL 25
230 X12
231 *
232 RCL 21
233 *
234 RCL 22
235 *
236 END

F=200.0E3
RS=4.00
VS=15.00
T0=1.251E-6
TD=20.00

PLOT OF PLTCL
X<UNITS= 1.> 4
Y<UNITS= E-2.> +
2.03 6.27
2.03

-20.01
-18.01
-16.01
-14.01
-12.01
-10.01
-8.01
-6.01
-4.01
-2.01
0.01
2.01
4.01
6.01
8.01
10.01
12.01
14.01
16.01
18.01
20.01

REACTIVE
CLOCK DRIVE

L=31.56E-6
QL=100.00
CL=5.000E-9

PMIN=20.33E-3
PMAX=52.73E-3

```

You can find the effective 10 to 90% rise and fall times for the reactive circuit from Eq 1 by using the following equation:

$$t_r, t_f = 0.59 \left( \frac{\pi}{\omega_0 B} \right).$$

Driving  $C_L$  with a conventional clock circuit produces the following power dissipation in the clock driver:

$$P_D = V_S^2 C_L f,$$

where  $f$  = clock frequency.

A thorough analysis of this reactive clock scheme yields this equation for the power dissipation:

$$P_D = V_S^2 C_L (1 - e^{-\pi Z}) f$$

where  $Z = \frac{R_S}{2\sqrt{\frac{C_L}{L}}}$

You should select inductor  $L$  based on the CCD's

capacitance,  $C_L$ , and your specified clock frequency. You should select  $Q_1$  and  $Q_2$  to have low on-resistance; on-resistance is not critical, however, for  $Q_3$  and  $Q_4$  as long as the  $C_L \times R_{ON}$  time constant is much less than the clock period. This restriction allows  $C_L$  to fully charge and discharge at the clock-voltage extremes.

The current through inductor  $L$  produces a voltage in the 10- $\mu$ F capacitor, which minimizes the average inductor current. This voltage, therefore, varies to compensate for timing differences or component variations.

The programs in Listing 1 run on a Hewlett-Packard HP41CV calculator and its companion printer, the HP82143A. The first program, labelled RCLK, computes the power loss for the nonreactive and reactive clock circuits, and graphs the results. The second program, PLATT, displays the circuit's power loss as a function of ring time.

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## CMOS buffer has low quiescent current

W F McClelland

*Electronic Resources, Stamford, CT*

The CMOS digital power buffer shown in **Fig 1** delivers almost any current level up to hundreds of amperes yet draws no quiescent current and is totally immune to latchup. The circuit uses four MOSFETs, two of which are low-current drivers. You can size the output power MOSFETs to suit your application.

When the input signal changes state, R limits the current through Q<sub>1</sub> and Q<sub>2</sub> for the few nanoseconds that both transistors are on. When the input settles to its new state, the output transistor that had been turned on charges its gate capacitance through R, thus delaying its turn-on time by a time determined by R. If speed is not a consideration in your application, you can make R very large, resulting in minuscule quiescent-power consumption. If you choose R to be too low a value in order to increase the switching speed, R could overheat if you allow the input to float. To correct for this float, add a 100-kΩ resistor from OUT to IN.

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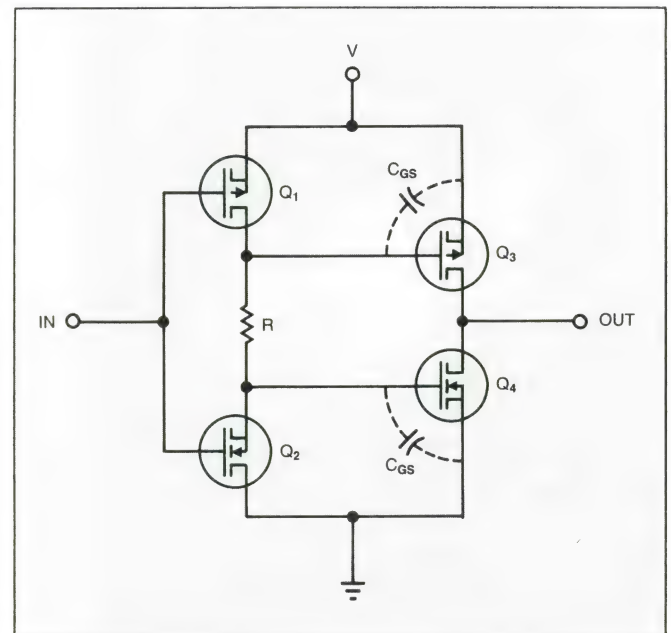
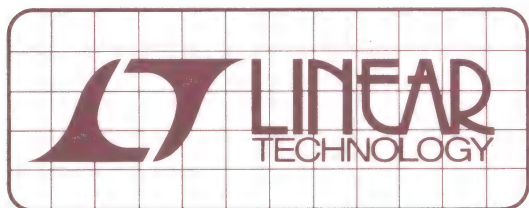


**Fig 1—This digital power buffer consumes virtually no quiescent current; the circuit consumes only enough current to charge a power MOSFET's input capacitance at each change of state of the input.**





# DESIGN NOTES

Number 19 in a series from Linear Technology Corporation

January, 1989

## A Two Wire Isolated and Powered 10-Bit Data Acquisition System

Guy Hoover and William Rempfer

### Introduction

For reasons of safety or to eliminate error producing ground loops, it is often necessary to provide electrical isolation between measurement points and the microprocessor. Unfortunately, the isolated side of this measurement system must still be provided with power. One alternative is to power the isolated side of the circuit with batteries. This solution works if power consumption is low, environmental conditions are mild and the batteries are easily accessible. If these conditions are not met a separate isolated supply may be constructed. This can be both difficult and expensive. This design note describes a transformer isolated system in which one small pulse transformer provides both power and a data path.

The circuit of Figure 1 is a 10-bit data acquisition system with 700V of isolation. The circuit takes advantage of the serial architecture of the LTC1092 which allows data and power to be transmitted using only one transformer. A 10-bit conversion can be completed and the data transferred to the microprocessor in 100 $\mu$ s. Using standard ribbon cable the isolated side of this circuit has been remotely located as much as 50 feet from the transformer without affecting circuit performance.

### Circuit Description

In Figure 1, a 4 $\mu$ s wide CS pulse clears the 74HC164 shift registers which will hold the D<sub>OUT</sub> word of the LTC1092. Additionally, the CS signal sends a 15V pulse through the transformer which charges the 1 $\mu$ f capacitor. The CS pulse width must be in the 2–6 $\mu$ s range for the transformer shown, a small Pulse Engineering model. A pulse more than 6 $\mu$ s will saturate the transformer while a pulse width of less than 2 $\mu$ s will not transfer enough energy through the transformer to keep the isolated supply from drooping during the conversion. The CS pulse can be generated with software or hardware. The LT1021-5 produces a regulated 5V at its output once the 1 $\mu$ f capacitor is charged to approximately 7.2V. The LT1021-5 regulated output powers the isolated side of the circuit. Initially several CS pulses may be required to charge the 1 $\mu$ f capacitor to 7.2V. Once charged however, only one CS pulse

per cycle is required to keep the isolated supply from drooping as long as the cycle is repeated every 100 $\mu$ s. The 15V CS signal is also attenuated and delayed. This signal is used to reset the clock circuit and begin the conversion of the LTC1092. The delay is required to allow the transformer fly-back to die out before transmitting the D<sub>OUT</sub> word of the LTC1092 across it.

The clock circuit is a simple oscillator that is gated by a combination of the CS signal and the 74HC161 counter so that for each CS signal the clock circuit generates 12 pulses and then is gated off. These 12 pulses are used to perform the A/D conversion and shift the D<sub>OUT</sub> word of the LTC1092 into the 74HC164 shift registers where the data can be acquired by the microprocessor.

The D<sub>OUT</sub> serial data of the LTC1092 is encoded with the clock, differentiated and sent across the transformer. The encoding circuitry pulse width modulates the LTC1092 output. The encoding circuitry uses two one shots to combine the data and the clock. For each negative going clock edge a positive pulse is produced at the output of the encoding circuitry. A wide pulse at the output of the encoding circuitry represents a logical 1 and a narrow pulse represents a logical 0 as shown in the timing diagram of Figure 2. The schottky diodes on the output of the 74HC04 capacitor driver are to protect the driver from damage caused by the initial 15V pulse and the resulting flyback.

The differentiated spikes from the transformer are "integrated" by the schmitt inverters and the 74HC74. Again, schottky diodes as well as current limiting resistors are used to protect the gates from transformer excursions beyond the supplies at their inputs. The encoded data is decoded by one half of the 74HC221 which reconstructs the clock. The 74HC164s convert the data to parallel format.

The 10k $\Omega$  pull-up resistor forces the output of the LTC1092 high when the A/D is in the high impedance state. When the A/D output becomes active a start bit (logic 0) is clocked out.



When this initial high to low transition is clocked into bit two of the second 74HC164 it triggers the one shot in the second half of the 74HC221 which provides a load data pulse for the microprocessor.

## Summary

The LTC1092 with its simple serial interface is ideally suited for this transformer isolation application. It requires only two isolated lines to transmit 10 bits of data. Additionally, during

the time when data is not being transmitted, power for the A/D can be sent through these lines. The circuit provides 700V of isolation and can perform a conversion and shift the data in 100 $\mu$ s. The isolated portion of the circuit can be remotely located up to 50 feet away using ordinary ribbon cable. Possible applications for this circuit are PC-based measurement systems, medical instrumentation, automotive or industrial control loops and other areas where ground loops or large common mode voltages are present.

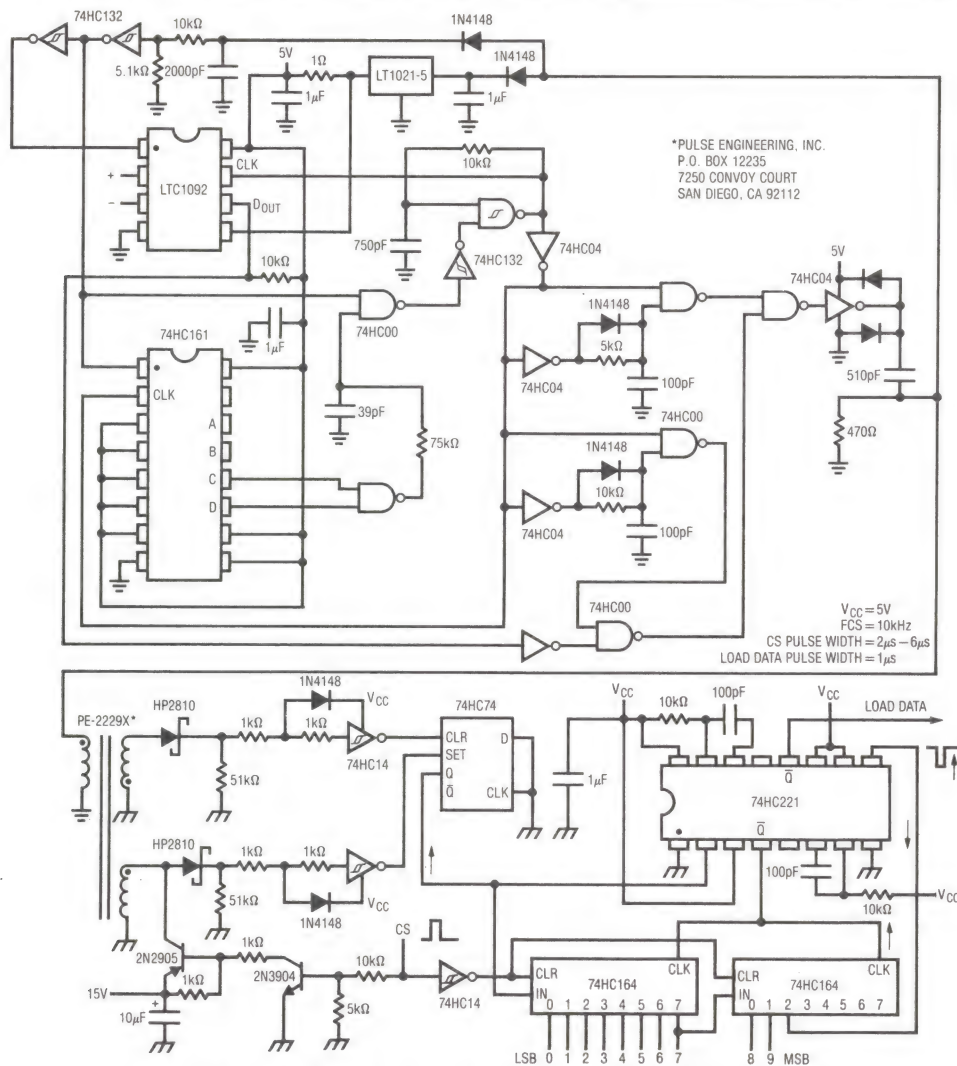


Figure 1. Power and 10-Bit A/D Result Transmitted over Two Isolated Lines

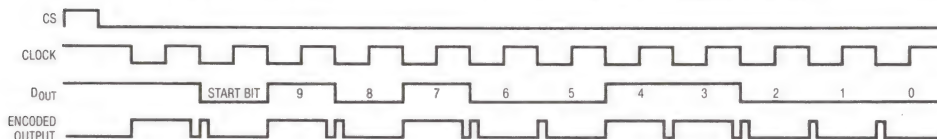


Figure 2. Timing Diagram Shows Pulse Width Coding Technique

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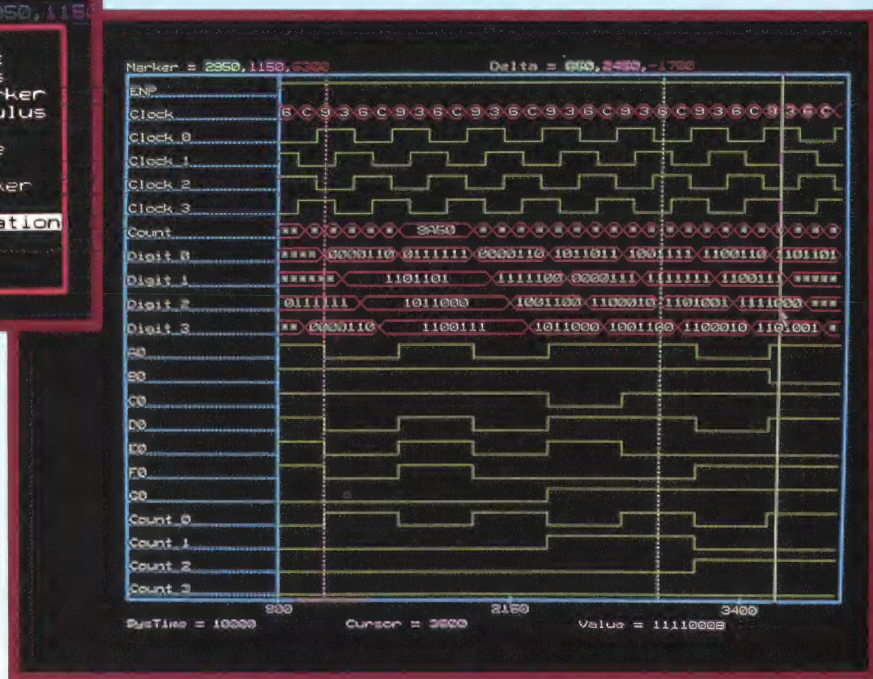
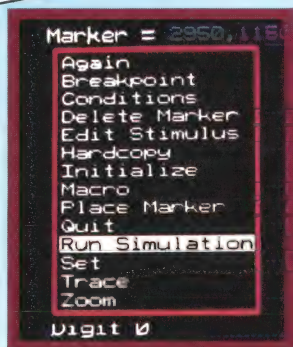
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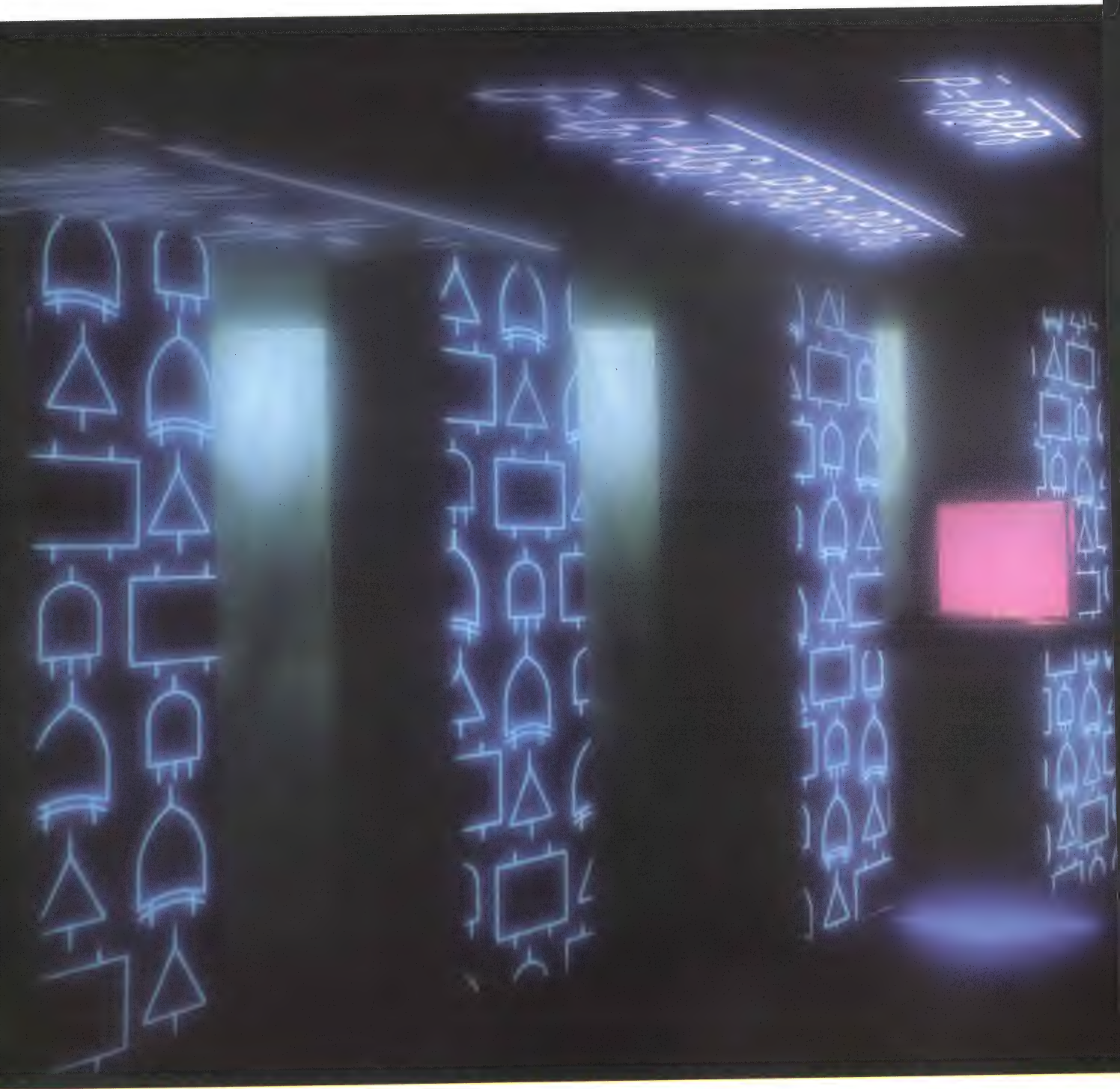
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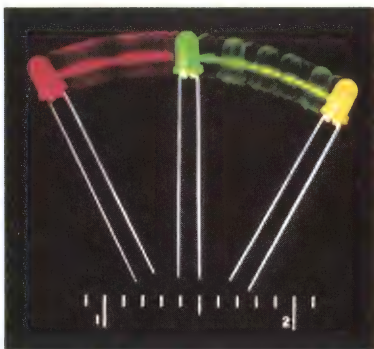
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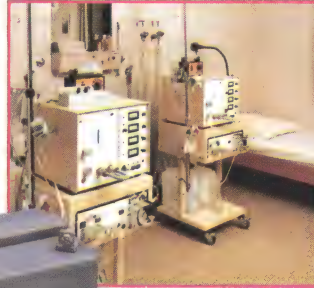
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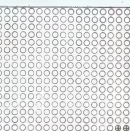
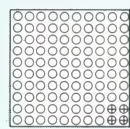
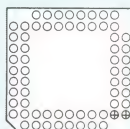
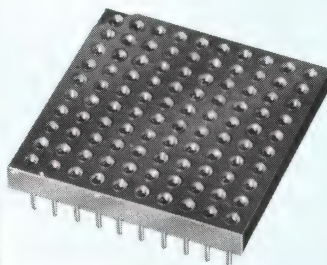
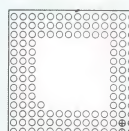
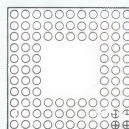
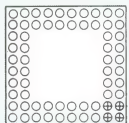
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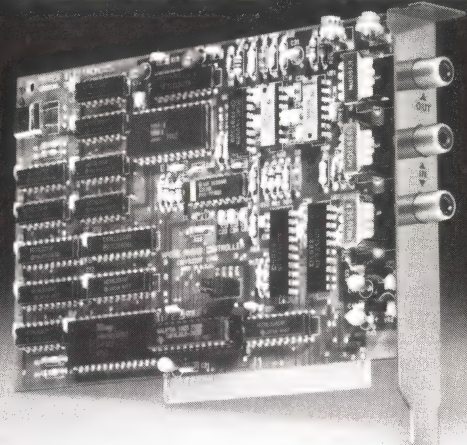
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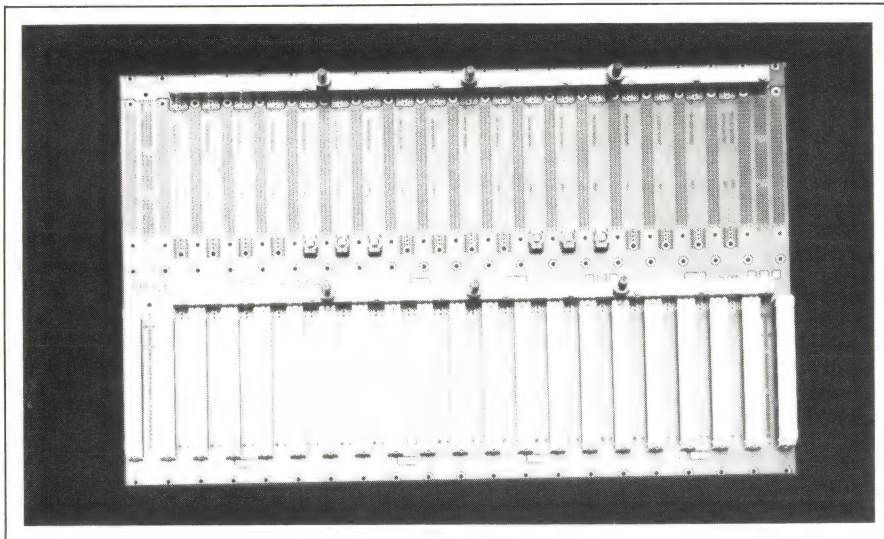
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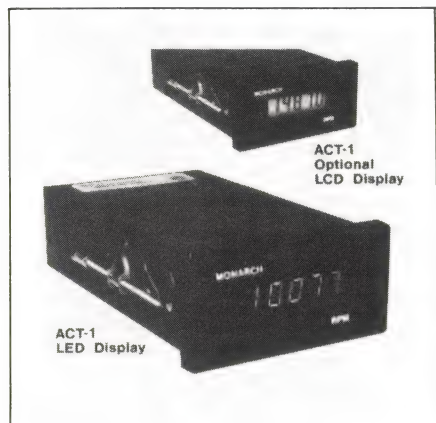


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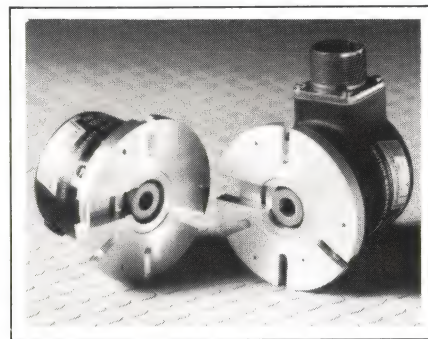
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the need for a pilot hole. The units employ an LED light source and a monolithic radial phototransistor array. Since all sensors are on the silicon chip, sensitivity to temperature and aging effects are minimized. The radial layout also minimizes sensitivity to disk runout and shaft-load variations. The encoders feature a 2540-cycles/revolution resolution and are compatible with TTL, CMOS, 3-state, and RS-422 interfaces. They operate from 5 to 15V supply levels and provide a quadrature output plus an index pulse. The encoders are available in instrument grade and ruggedized



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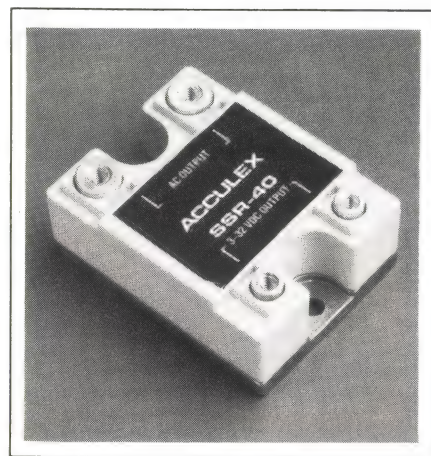
## KEITHLEY

## COMPONENTS & POWER SUPPLIES

industrial grade housings with MIL-type connectors to accommodate harsh industrial environments. Delivery, eight to 10 weeks ARO. \$267.

**PMI Motion Technologies**, 49 Mall Dr, Commack, NY 11725. Phone (516) 864-1000. TLX 510-223-0007.

Circle No 353



## SOLID-STATE RELAYS

- *Switching capability ranges to 40A*
- *Reliability greater than 20-million device hours*

SSR-10, -20, and -40 solid-state relays switch loads of 10, 20, and 40A at 24 to 280V ac, respectively. Control input requirements range from 3 to 28V dc at 250 mA. All three versions feature zero-voltage turn-on and zero-current turn-off to virtually eliminate EMI/RFI problems. Turn-on and turn-off times are 8 msec max. Optical isolation is 4000V rms; dielectric strength is 3700V. Surge current ratings for the -10, -20, and -40 relays equal 100, 200, and 650A, respectively. A built-in snubber protects against false triggering. The relays are housed in industry-standard packages measuring 1.75 x 2.25 x 0.90 in. SSR-10, \$34; SSR-20, \$38; SSR-40, \$46.

**Acculex**, 440 Myles Standish Blvd, Taunton, MA 02780. Phone (508) 880-3660. TLX 503989.

Circle No 354





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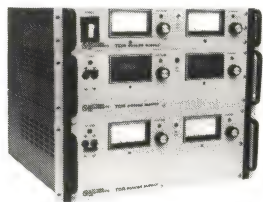


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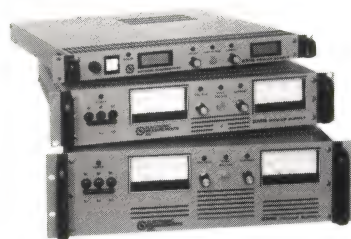
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CIRCLE NO 16

## COMPONENTS & POWER SUPPLIES



### PROCESS METER

- Offers a 3 1/2-digit display span
- Signal ranges are jumper selectable

The 205-P digital process meter features 0.56-in.-high characters and includes a power supply. Potentiometers allow you to achieve 2000-count zero and span adjustments from the meter's front panel. Full-scale signal ranges of 4 to 20 mA, 0 to 199.9 mV, 1 to 5V, 0 to 10V, and 0 to 100V are jumper selectable. The input is true differential and features 56 dB of normal-mode noise rejection. The meter operates from ac (24, 100, 115, or 230V) or dc (5 or 7 to 32V) power sources and is housed in a polycarbonate plastic case, which carries a 94V-0 UL rating. From \$139.

Newport Electronics Inc., 630 E Young St., Santa Ana, CA 92705. Phone (714) 540-4914. FAX 714-546-3022.

Circle No 355

### DC/DC CONVERTER

- Uses bipolar switched-capacitor technology
- Available in a variety of package styles

The LT1026 dc/dc converter transforms a single-level input into a dual, higher-voltage output. The device uses bipolar switched-capacitor technology, negating the need for internal inductors. The converter has a 4 to 10V input range and will output voltages as high as  $\pm 18V$ . The maximum output current is 20 mA. The unit requires only 1- $\mu F$  charge pump capacitors. The converter comes in a plastic or ceramic DIP, a TO-5 metal can, and an 8-pin miniature DIP. An LT1026

in a miniature DIP, \$2.10 (100).

Linear Technology Corp., 1630 McCarthy Blvd, Milpitas, CA 95035. Phone (408) 432-1900. FAX 408-434-0507.

Circle No 356



### DC/DC CONVERTERS

- Provide single and dual outputs
- Have a 75% efficiency rating

Suited to high-energy applications, R-Series 15W dc/dc converters accept inputs of 10 to 40V dc. Single-output models provide from 30 to 1800V dc and dual-output versions generate outputs from  $\pm 15$  to  $\pm 900V$  dc. All units are housed in a 2.5  $\times$  3.02-in. package that features short-circuit protection. The converters have a built-in pi filter and a 75% typ efficiency rating. Switching frequency is 60 kHz and input-to-output isolation is equal to the output voltage plus 500V. Other specifications include a  $1 \times 10^9 \Omega$  min resistance, 50-pF I/O capacitance, and 3% line and load regulation. Single-output models, \$185 (100).

MIL Electronics Inc., 1 Mill St, Dracut, MA 01826. Phone (508) 453-8000.

Circle No 357

### PANEL METERS

- Feature 0.01% accuracy
  - Accommodate a variety of inputs
- Housed in a 1/8-DIN package, the 60 Series digital panel meters feature a 0.01% measurement accuracy. Models are available with 3 1/2- and 4 1/2-digit resolution. The choice of inputs includes various thermocouples, RTD, dc volts or amps, ac volts or amps, and process-level



volts or amps. Two RTD models and J-, K-, T-, and E-type thermocouples are available for temperature ranges of  $-200$  to  $+1200^{\circ}\text{C}$  or  $-328$  to  $+1999^{\circ}\text{F}$ . The meter can scale common process inputs such as 0 to 5V dc, 1 to 5V dc, and 4 to 20 mA directly to engineering unit displays. The meters will handle linear ac and dc inputs ranging



from 1 to 600V and from microamps to 200 mA. From \$104.

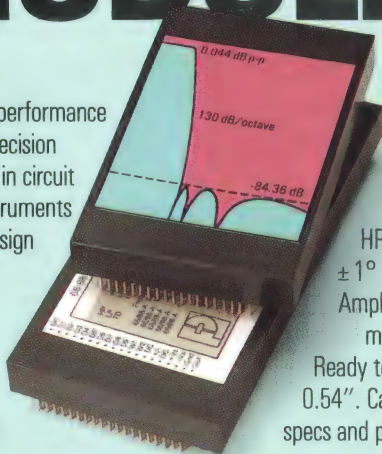
**Beckman Industrial Corp**, 3883 Ruffin Rd, San Diego, CA 92123. Phone (619) 495-3236.

Circle No 358

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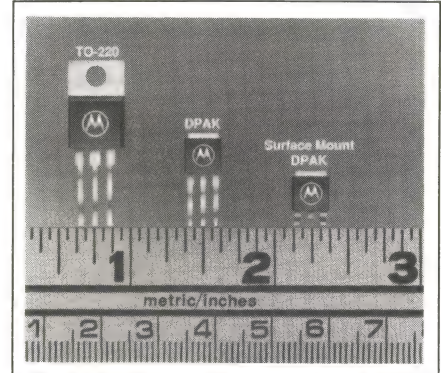
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CIRCLE NO 17



### POWER MOSFETs

- Feature logic-level drive compatibility
- Available in surface-mount packages

The MTD3055EL and MTP3055EL power MOSFETs have a low threshold voltage (fully on with a 5V drive), which allows you to design power-control circuits that you can drive directly from 5V logic ICs,  $\mu\text{Ps}$ , or any other low-voltage source. The MTD3055EL version is available in a surface-mount package and the MTP3055EL version comes in a TO-200 package. Both versions have a 60V breakdown specification, a 12A drain-current rating at  $25^{\circ}\text{C}$ , and an on-resistance of  $0.18\Omega$  max at a 6A drain current. MTD3055EL, \$0.69; MTP3055EL, \$0.63 (100).

**Motorola Inc**, 5005 E McDowell Rd, Phoenix, AZ 85008. Phone (602) 244-4911.

Circle No 359

### CHIP RESISTORS

- Available on 8-mm reels
- Operate from  $-55$  to  $+125^{\circ}\text{C}$

TNPW1206 chip resistors are available on 8-mm reel packages for use with automatic placement equipment. The resistors are reflow solderable and feature wraparound



terminations. Termination reliability is enhanced by a nickel barrier, which protects the inner electrode. The barrier is covered with a solderable coating. Designed to operate over a  $-55$  to  $+125^{\circ}\text{C}$  range, the resistors have a 125-mW power rating at  $70^{\circ}\text{C}$  and an operating voltage of 100V max. Resistance values range from  $50\Omega$  to  $100\text{ k}\Omega$  for units with a 0.5% tolerance and from 1 to  $100\text{ k}\Omega$  for devices with a 0.1% tolerance. Both lines have a 25-ppm/ $^{\circ}\text{C}$  temperature coefficient. Unit with 0.1% tolerance, \$0.55 (10,000). Delivery, stock to six weeks ARO.

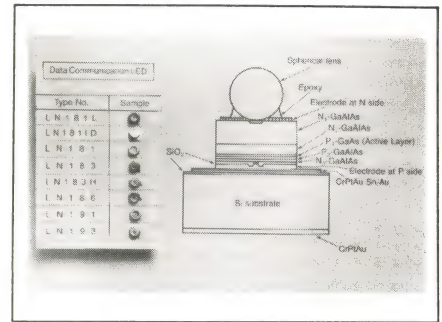
**Dale Electronics Inc.**, Box 74, Norfolk, NE 68701. Phone (402) 371-0080.

Circle No 360

## HIGH-SPEED LEDs

- Have a  $10^6$ -hour life
- Handle short- and long-wavelength applications

The LN Series high-speed LEDs satisfy 0.8- and  $1.3\text{-}\mu\text{m}$ -wavelength applications. The units employ a double hetero structure, current confinement, and spherical lenses that are mounted on the chip. These



# THE BATTERY FOR AUTOMATED PRODUCTION IS NOW IN PRODUCTION

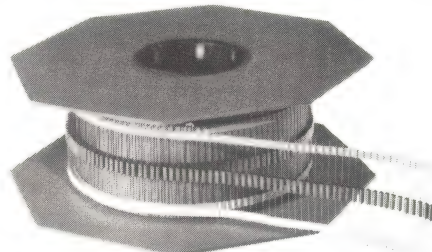


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The B-35 has 35 milliamps-hours capacity. Enough for most CMOS backup applications. Although not tape mounted, higher capacity models (to 1 amp-hour) are available with all the other production advantages of the B-35.

For more information, call (301) 296-7000, ext. 304.



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1421 Clarkview Road Baltimore, MD 21209-9987 (301) 296-7000 ext 304

## A/D CONVERTER

- Features integral S/H amp
- Has a  $1\text{-}\mu\text{sec}$  throughput

The ADC16M1 16-bit 1-MHz A/D converter plug-in module consists of three pc boards plugged together. It features a design employing a 3-step foldback conversion technique with a transparent partial pipeline to achieve its  $1\text{-}\mu\text{sec}$  throughput rate. The high-impedance input circuitry consists of two independent S/H amps operated alternately with a ping-pong switch and a buffer amplifier. Linearity error equals  $\pm 0.002\%$  FSR. The unit is available in commercial, industrial, and quasi-MIL grades. Commercial version, \$2895.

**Hopper Electronics Co.**, 341 E Camelback, #D, Phoenix, AZ 85012. Phone (602) 266-2687.

Circle No 361



features result in a coupling efficiency of 3% for the micro-lens type LN183 and LN193 units and 4% for the LN181 and LN191 flat-lens types. Cutoff frequency is 35 MHz for the GaAlAs LEDs in the 0.8- $\mu$ m region (LN181 and -183) and 100 MHz for the InGaAsP units in the 1.3- $\mu$ m region (LN191 and -193). \$50 to \$150. Delivery, 10 to 12 weeks ARO.

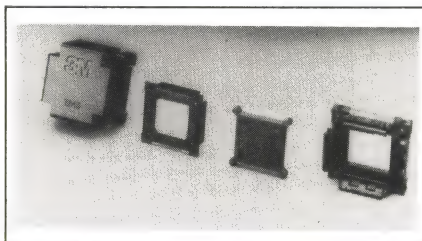
**Panasonic Industrial Co., 2**  
Panasonic Way, Secaucus, NJ  
07094. Phone (201) 348-7000.

Circle No 362

### FLAT-PACK SOCKETS

- Accommodate flat packs with as many as 164 leads
- Operate from  $-55$  to  $+125^{\circ}\text{C}$

These end-use sockets are designed for plastic quad-flat-pack devices. Socket contacts are on 0.025-in. centers. Units that accommodate flat packs with 84, 100, 132, and 164



leads are available. The design of the socket body and lid protects  $\mu$ Ps during handling, loading, and end use. You can apply the lids to the  $\mu$ Ps while they are still in IC handling trays. Tines in the lid grip gull-wing packages for pick-and-place or manual-handling operations. The body latches audibly snap into lid grooves to secure the lid/package assembly. A latching tool ensures manual alignment and insertion of the lid/flat-pack assembly into the socket. By applying downward pressure to the tool, you load the device and securely close the hinged socket latches around the lid. The sockets will operate

over a range of  $-55$  to  $125^{\circ}\text{C}$ . 100-position socket, \$14.38 (100).

**3M, Electronic Products Div,**  
Box 2963, Austin, TX 78769. Phone  
(512) 834-6563.

Circle No 363

### DRY-CIRCUIT RELAY

- Is pc-board mountable
- Suits appliances, office machines, and audio equipment

The TZ is a dry-circuit-type single X-bar contact pc-board-mountable relay. It features a 1500V ac breakdown voltage and a 3000V surge resistance between coil and contact. Contact material is silver palladium overlaid gold for dry-circuit switching. The relays will switch 1A at 24V dc or 120V ac. Coil voltage ratings range from 3 to 24V dc. Standard coil sensitivity at nominal operating voltages is 107 mA. The relays have a  $-25$  to  $+60^{\circ}\text{C}$  operating range and a 100,000 operations

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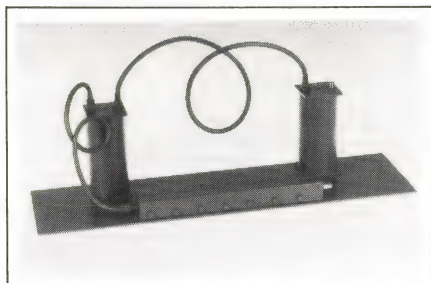
MAXI/PC can tackle your toughest boards—dual in-line, multilayer designs, as well as double-sided, surface-mount designs. Powerful features such as automatic component placement, automatic



lifetime at rated load. The relays conform to UL, CSA, and FCC Part 68 requirements. \$0.96 (1000). Delivery, four to six weeks ARO.

**Original Electric Mfg Co Inc,**  
123 Lincoln Blvd, Middlesex, NJ  
08846. Phone (201) 271-5770.

**Circle No 364**



### BANDPASS FILTER

- Isolates the FM band
- Provides a 75Ω impedance

The sharp skirts of the 6067 band-pass filter isolate the FM band from video signals. The filter's passband ranges from 89 to 108 MHz. Loss

is 5 dB max at 89 MHz and less than 2 dB throughout the rest of the passband. Rejection measures 35 dB min from 0 to 87.75 MHz and 50 dB min from 121.25 to 450 MHz. The 6067 comes with type F connectors and is mounted on a standard 19-in. rack panel for indoor use. The filter is also available in a weatherized housing for outdoor use. \$450.

**Microwave Filter Co,** 6743  
Kinne St, East Syracuse, NY  
13057. Phone (800) 448-1666.

**Circle No 365**

### ZIP CABLE

- Handles severe environments
- Features 10 to 64 conductors

Thermoplastic elastomer (TPE) insulated zip cable is available in sizes from 10 through 64 conductors. The thermoplastic elastomer insulation allows you to operate this cable over -65 to +125°C. Cable construction consists of 28-7 AWG



tinned-copper conductors on 0.050-in. center spacings. One edge of the cable is marked for polarity reference. UL recognized at a rating of 125°C and 300V, the cable is available on 100-ft put-ups. A 10-conductor cable, \$18.69 (10).

**Amphenol Spectra-Strip,** 720  
Sherman Ave, Hamden, CT 06514.  
Phone (800) 572-2253; in CT, (203)  
281-3200.

**Circle No 366**

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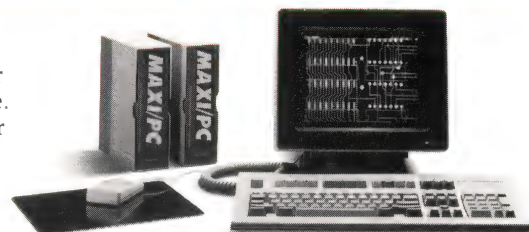
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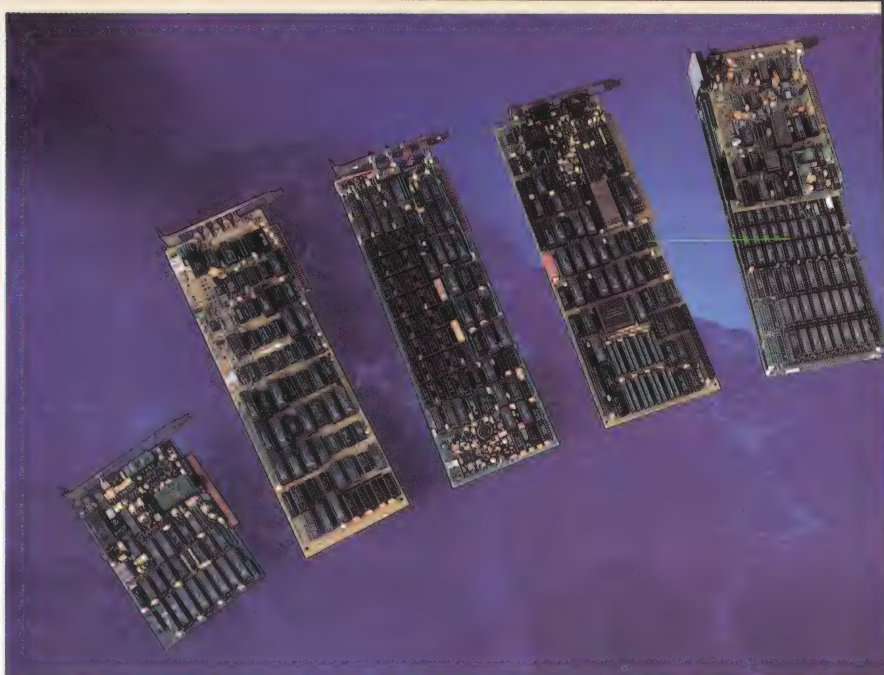


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| <b>OCULUS-150</b> | PC  | 512 x 512                                   | 1 BIT                                           | 30                | 32 KB              | NO          | NO           | YES              | NO               | \$ 1545      |
| <b>OCULUS-200</b> | PC  | 512 x 512                                   | 7 BITS                                          | 30                | 256 KB             | YES         | NO           | NO               | NO               | \$ 1295      |
| <b>OCULUS-300</b> | AT  | PROGRAMMABLE UP TO 1024 x 512 OR 512 x 1024 | 8 BITS (MONOCHROME) 24 BITS (TRUE COLOR OPTION) | 30 TO 120         | UP TO 2 MB         | YES         | YES          | YES <sup>1</sup> | YES <sup>2</sup> | FROM \$ 1795 |
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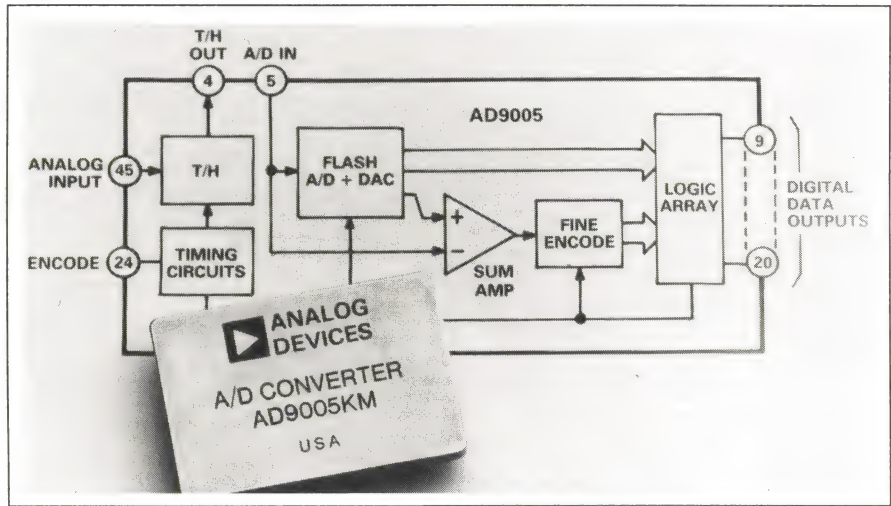
# NEW PRODUCTS

## INTEGRATED CIRCUITS

### 12-BIT A/D CONVERTER

- Low power-dissipation
- Sample rates to 10M samples/sec

Available in a 46-pin package, the AD9005 is a complete 12-bit hybrid A/D converter (ADC) that dissipates 3.4W of power—33 to 50% less than competitive versions, according to the manufacturer. The AD9005 features an onboard track-and-hold amplifier, a voltage reference, TTL timing circuitry, and output latches. The ADC uses a subranging architecture that samples inputs to 10M samples/sec. It also has a maximum transient response of 120 nsec and an overvoltage recovery time of 150 nsec at 25°C. Differential nonlinearity and integral nonlinearity are 0.75 LSB and 2.0 LSB, respectively. With a

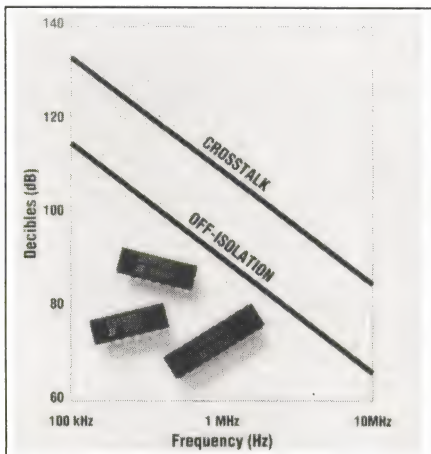


frequency input of 4.3 MHz, in-band harmonics are -66 dB min, and signal-to-noise ratio is -61 dB min. The AD9005 is available in commercial and military grades. \$800 and

\$1400 (100).

**Analog Devices**, Literature Center, 70 Shawmut Rd, Canton, MA 02021. Phone (617) 935-5565.

Circle No 370



### ANALOG SWITCHES

- Optimized for high-frequency operation
- Available in dual and quad versions

Fabricated in DMOS/CMOS technology, the DG540, DG541, and DG542 analog switches are TTL compatible and feature bandwidths to 500 MHz. Available in dual and quad versions, the devices provide 5 MHz off-isolation to -80 dB and crosstalk of -85 dB. The quad DG540 and DG541 are both spst

switches. The DG541 comes in a 16-pin package. The 20-pin DG540 includes extra ground lines between the signal pins to improve off-isolation and reduce crosstalk. The dual DG542, which also comes in a 16-pin package, has four analog switches configured as two spdt functions. You can use each spdt switch as a selector between two channels, allowing the DG542 to handle two sets of video signals simultaneously. From \$3.93 to \$15.83 (100).

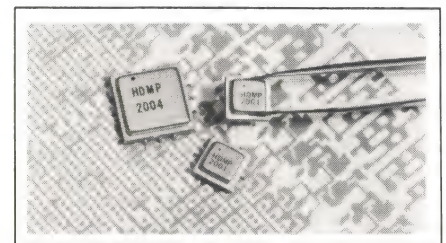
**Siliconix Inc**, 2201 Laurelwood Rd, Santa Clara, CA 95054. Phone (408) 988-8000.

Circle No 371

### DECISION CIRCUITS

- Regenerate digital waveforms
- Operate at 1.5 and 2.8 GHz

Available in low-inductance, surface-mount packages, the 1.5-GHz HDMP-2001 and the 2.8-GHz HDMP-2004 decision circuits regenerate digital waveforms in fiber-optic transmission systems. Each



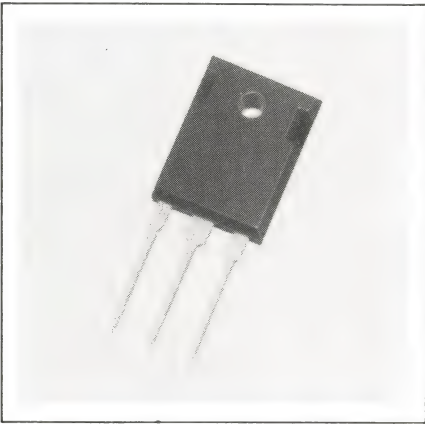
circuit samples the stream of G-bit data, measures the amplitude and timing, decides whether the bit is a ONE or a ZERO, and retimes and regenerates the digital waveform. The 12-pin HDMP-2004 is suited to 2.4G-bit/sec, long-haul systems currently under development. The 6-pin HDMP-2001 is designed for data rates from 400M bits/sec to 1.5G bits/sec and can be retrofitted into existing applications. Unlike the HDMP-2004, the HDMP-2001 requires external coupling capacitors and temperature compensation. HDMP-2001, \$75; HDMP-2004, \$350 (1-9).

**Hewlett Packard Co**, 19310 Pruneridge Ave, Cupertino, CA 95014. Phone local office.

Circle No 372



## INTEGRATED CIRCUITS



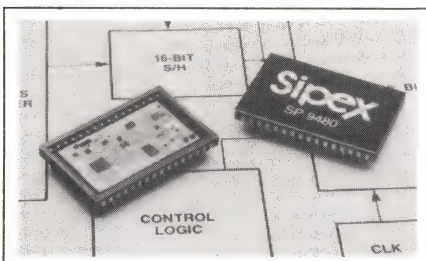
### 5V REGULATOR

- Rated at 5A load current
- Comes in TO-247 package

The LAS1905P linear regulator provides a fixed voltage of 5V at a load current to 5A. The device features internal current limiting, thermal shutdown, and on-chip safe-area protection of the series-pass Darlington transistor. The LAS1905P also contains a low-noise, temperature-stable bandgap reference. The TO-247-packaged device can be either manually or automatically inserted on a pc board. \$3.87 (1000).

**Lambda Semiconductors**, 121 International Blvd, Corpus Christie, TX 78060. Phone (512) 289-0403.

Circle No 373



### DATA ACQUISITION IC

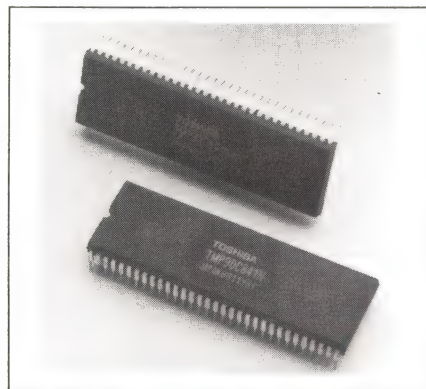
- Comes in 32-pin hermetic package
- Multichannel 16-bit system

The SP9480, which comes in a 32-pin hermetically sealed package, is a completely integrated multichannel data-acquisition system (DAS). The hybrid IC contains an 8-channel multiplexer, a 16-bit sample-hold amplifier, a 16-bit A/D converter,

a reference, a clock, and 3-state outputs. The SP9480 has a throughput of 30 kHz for full-rated accuracy. Each of the eight single-ended input channels provide 0 to 10V and  $\pm 10V$  input ranges. Signal-acquisition time, which includes multiplexer-switching and sample-hold times, is 15  $\mu\text{sec}$  max. Sample-hold specifications include an aperture delay of 25 nsec and a droop rate of 0.025  $\mu\text{V}/\mu\text{sec}$ . The 16-bit ADC converts in 25  $\mu\text{sec}$  max. Integral and differential linearity for the entire system is specified at  $\pm 0.003\%$  with a drift of  $\pm 2$  ppm/ $^{\circ}\text{C}$ . The SP9480 is available in two accuracy grades and two temperature ranges. Delivery, stock to 10 weeks ARO. \$229 to \$395 (100).

**SipeX Corp**, 22 Linnell Circle, Suburban Industrial Park, Billerica, MA 01821. Phone (508) 667-8700. FAX 508-667-8310.

Circle No 374



### MICROCONTROLLER

- Includes an 8-bit CPU
- Features 163 basic instructions

The TMP90C840 combines an 8-bit central-processing unit (CPU) with 8k bytes of ROM, 256 bytes of RAM, an 8-bit A/D converter, a multifunction 16-bit timer/counter, I/O ports, and a serial interface. Managed by an 11-channel direct-memory-access controller, external program memory can reach 56k bytes and external data memory can reach 1M byte. The device features 163 basic instructions, including 16-bit arithmetic operations. It has a minimum instruction execu-

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Quality Components (NY) (315) 682-8885  
(716) 837-5430

#### SOUTHEAST:

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(813) 886-2457  
Design Marketing & Assoc. (TX) (214) 480-8151  
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(512) 263-9151  
(713) 550-3318

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R.O. Whitesell & Assoc. (AL) (205) 883-5110  
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#### MIDWEST:

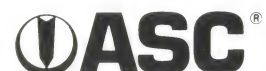
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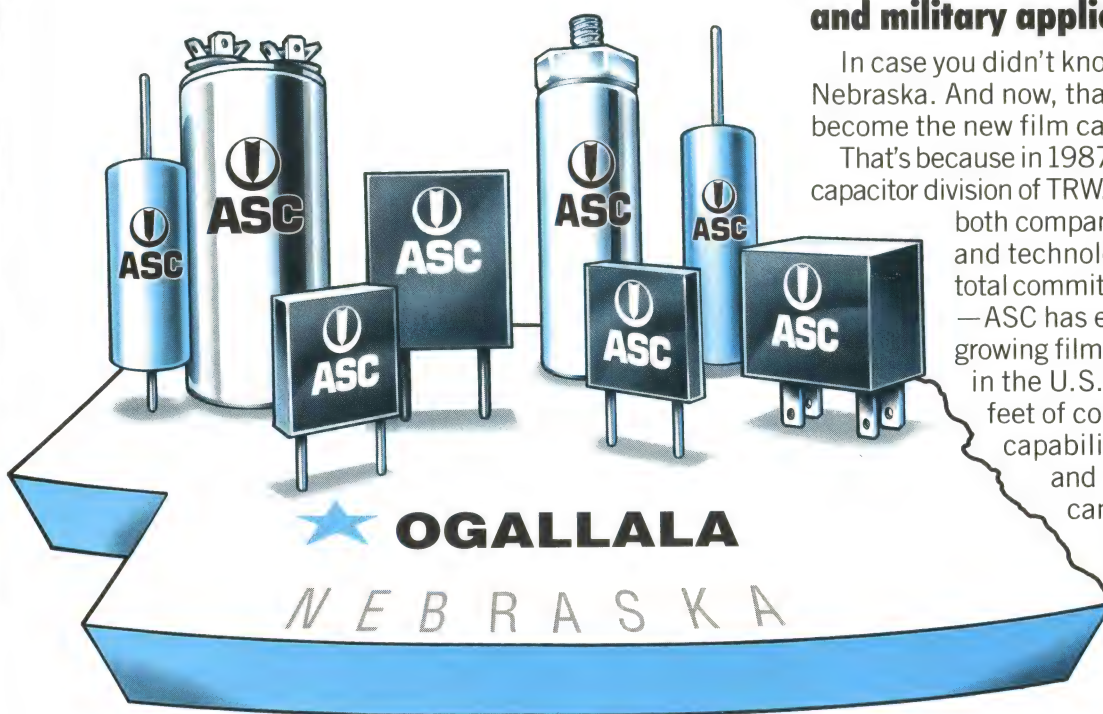
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Sales & Marketing, Canoga Park, California  
Engineering & Manufacturing, Ogallala, Nebraska  
ASC, 21541 Blythe Street, Canoga Park, CA 91304



tion time of 400 nsec with a 10-MHz clock. The CMOS device operates from a single 5V supply and dissipates 250 mW. It comes in a plastic DIP or a quad flat pack. \$9.50 (5000).

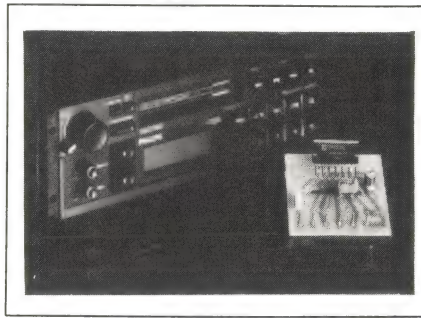
**Toshiba America Inc.**, 9775 Toledo Way, Irvine, CA 92718. Phone (714) 455-2000.

Circle No 375

## POWER AMPLIFIERS

- Provide 22W of output power
- Operate from 6 to 18V supply

Using few external components, the TDA1516Q and TDA1518Q class-B audio power amplifiers provide a power output of 22W (mono) or 11W (stereo). Designed for automotive applications operating from a 6 to 18V supply, the ICs include an on-chip mute function that eliminates audible switch-on and -off clicks and a standby mode that re-



duces quiescent current from 30 mA to  $<100 \mu\text{A}$ . The TDA1516Q, which is suitable for use in booster amplifiers, has 20 dB of gain; the TDA1518Q, designed for car radios, has 40 dB of gain. The ICs feature internal protection against load-dump, short-circuits, and over-temperature conditions. The ICs are packaged in 13-pin single in-line packages, and the pins are bent to dual in-line configuration to provide sufficient lead separation for pc-board mounting. Hfl 3.50 (OEM qty).

**Signetics Corp.**, 811 E Arques

Ave, Sunnyvale, CA 94088. Phone (408) 991-2000.

Circle No 376

**Philips Components**, Box 218, 5600 MD Eindhoven, The Netherlands. Phone 31-40-756181.

Circle No 377

## SEMICUSTOM SMPS IC

- Uses system-level core technology
- Provides basic elements for SMPS control

The FB3480 semicustom array consists of a core group of interconnected cells to form a high-performance pulse-width-modulator (PWM) controller for switch-mode power supplies (SMPS) requiring as much as 1 MHz. The array is implemented on a 36V bipolar process. The FB3480's core cells include a precision voltage reference; an oscillator; an error amplifier; and two totem-pole, high-current output stages optimized for high-frequency opera-

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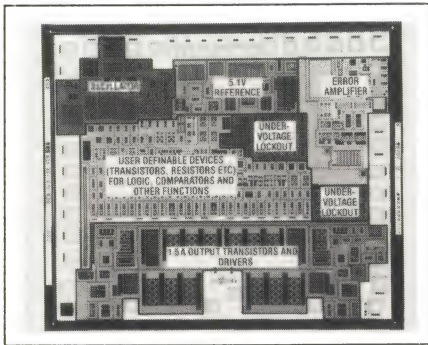
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Circle 42 for Product information

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tion. The FB3480 also contains several clusters of uncommitted transistors, resistors, and capacitors that you can connect to form higher-level functions, using the company's library of soft macrocells. NRE charges of \$7500, which include 50 customized prototypes, are contingent on a minimum production commitment of \$25,000 worth of parts. Unit price, around \$5.00.

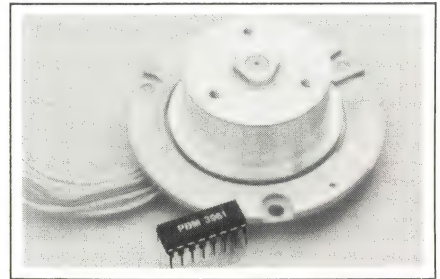
**Micro Linear Corp.**, 2092 Concourse Dr., San Jose, CA 95131. Phone (408) 433-5200.

Circle No 378

## MOTOR CONTROLLER

- Controls the speed of brushless dc motors
- Requires no external passive components

The PBM3961 motor controller regulates the speed of 3-phase, 4-pole, brushless dc motors and includes functions to start, stop, and reverse the motor. Apart from the H-bridge power MOSFETs that drive the motor's phase windings, the controller doesn't require any external components. The device is optimized to drive a 3600-rpm disk-drive motor, using a 4-MHz reference-clock input. However, you can operate it satisfactorily at motor speeds between 1800 and 7200 rpm by altering the clock frequency. It accepts inputs from the motor's three Hall-effect sensors and provides closed-loop control of the motor speed. All loop filtering is performed digitally within the device, which uses pulse-width-modulation



(PWM) switching to control the current in the motor's phase windings. By adding a resistor in the ground lead of the H-bridge drivers and by using the PBM3961's level-sensitive disable input, you can limit the start-up current of the motor. A delay circuit in the device's direction-control input prevents cross-conduction of the H-bridge transistors when you reverse or brake the motor. The device's PWM outputs can directly drive H-bridge MOSFETs operating from a supply voltage as high as 12V. A TTL-level output indicates when the motor has settled within  $\pm 0.7\%$  of its correct





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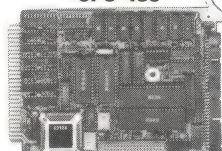
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**PAGE 278**

## INTEGRATED CIRCUITS

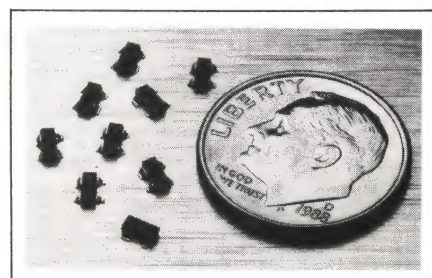
value. The PBM3961 is available in a 16-pin DIP or small-outline, surface-mount packages. \$3 (10,000).

**Ericsson Components AB**, Isaffjordsgatan 16, 16481 Kista-Stockholm, Sweden. Phone (08) 757-4354. FAX 08-752-6034.

Circle No 379

**Ericsson Components**, 403 International Parkway, Richardson, TX 75085. Phone (214) 480-8300. FAX 214-680-1059.

Circle No 380



## MMIC AMPLIFIERS

- *Characterized at 500 MHz*
- *Come in SOT-143 surface-mount packages*

The MSA series of cascadable 500 gain blocks are monolithic microwave integrated circuits (MMICs) suited to narrow- or wide-bandwidth RF applications. To achieve high performance and reliability, the chips are fabricated in a 10-GHz silicon bipolar process, which features nitride passivation, ion implantation, and gold metalization. Each of the three devices in the series comes in a low-cost, surface-mount SOT-143 package. At 500 MHz, the MSA-0311 features an 11½-dB gain, a 10-dBm power output and a 5½-dB noise figure; the MSA-0611 has an 18-dB gain, a 2-dBm power output, and a 3-dB noise figure; the MSA-0711 has a 12½-dB gain, a 5½-dBm power output, and a 5-dB noise figure. The devices are available on 7-in. or 13-in. reels containing 3000 and 10,000 devices, respectively. \$3.

**Avantek**, 3175 Bowers Ave, Santa Clara, CA 95054. Phone (408) 970-2659.

Circle No 381



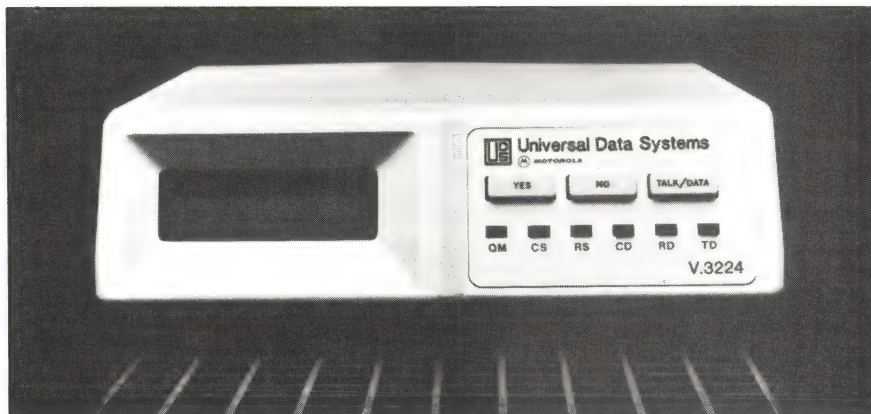
# NEW PRODUCTS

## COMPUTERS & PERIPHERALS

### V.32 MODEM

- Full duplex at 9600 bps with MNP level 5 ECC
- Supports CCITT V.29 and V.22bis specifications

The V.3224 modem fully supports the CCITT V.32, V.29, and V.22bis standards for full- and half-duplex 9600-, 4800-, 2400-, and 1200-bps synchronous and asynchronous communication. Full-duplex 9600-bps communication utilizes a patent-pending echo-cancellation technique, a trellis-coded error-correction scheme, and support for MNP level 5 error checking and correction (ECC). The modem also features automatic adaptive equalization, tone or pulse dialing, call-progress monitoring, and internal



diagnostics. The unit can store as many as nine frequently used telephone numbers in nonvolatile memory. The modem can autoanswer and autodial, using the industry-standard IBM PC AT command set. The V.3224 is available in rack-

mount and desk-top versions. \$1145.

**Universal Data Systems**, 5000 Bradford Dr, Huntsville, AL 35805. Phone (205) 721-8000. FAX 205-830-5657. TWX 810-726-2100.

Circle No 415

### VECTOR PROCESSORS

- Deliver as many as 100M flops with dual 32-bit  $\mu$ Ps
- Attache to a variety of host processors

The VP (vector processing) Series vector processors mount in a standard 19-in. rack and attach to a variety of host computers. The units are based on the company's 32-bit CMOS ST-50 processor. The VP-2A dual-processor system delivers as many as 100M flops. You can combine a number of VP-2 systems for linear improvement in performance; for example, three VP-2s deliver 300M flops. The series operates with host computers from IBM, Digital Equipment Corp (Unibus, Q Bus, VAXBI), Gould, Sun Microsystems, and Alliant Computer Systems. The series has an aggregate main-memory bandwidth of 100M bytes/sec, and it supports 50M byte/sec data transfers with the host over a DMA channel for real-time applications. In addition, multiple I/O processors can attach to the host, permitting data transfers at 12.5M bytes/sec. 100M-flops

system, \$95,000. Delivery, 90 days ARO.

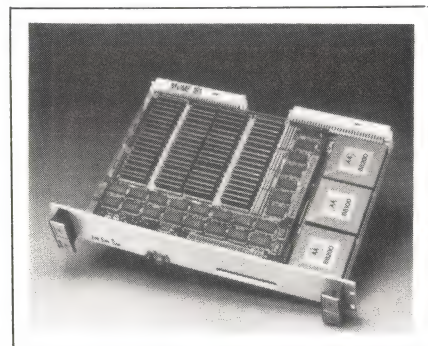
**Star Technologies Inc**, 515 Shaw Rd, Sterling, VA 22170. Phone (703) 689-4400.

Circle No 416

### VME RISC MODULE

- Has an MC88100 RISC  $\mu$ P operating at 20 or 25 MHz
- Has 8M bytes of RAM with parity

The MVME181 VME Bus module occupies two VME Bus slots. It contains an MC88100 RISC  $\mu$ P that operates at 20 or 25 MHz and delivers as many as 20 VAX MIPS. The CPU is tightly coupled to two MC88200 cache/memory-management units: one provides a 16k-byte instruction cache, and the other provides a 16k-byte data cache. The board has 8M bytes of RAM with parity. Cache refills are accomplished using a 2-way interleave and a 4-word state machine that implements the burst mode. A 32-bit VME Bus interface permits 8-, 16-, or 32-bit data transfers and 16-, 24-,

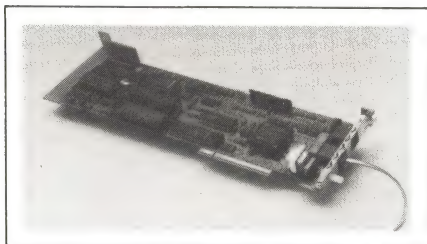


and 32-bit addressing. The board contains the complete system-controller functions, including a 4-level bus arbiter and a 7-level interrupt handler. Other onboard resources include two RS-232C asynchronous communications ports, a battery-backed calendar clock, a 16-bit programmable timer/counter, and four sockets for as much as 512k bytes of ROM, PROM, or EPROM. 20-MHz version, \$8995; 25-MHz version, \$9995.

**Motorola**, Microcomputer Div, Marcom Dept, DW283, 2900 S Diablo Way, Tempe, AZ 85282. Phone (800) 556-1234, ext 230; in CA (800) 441-2345, ext 230.

Circle No 417





## MCA MODEM BOARD

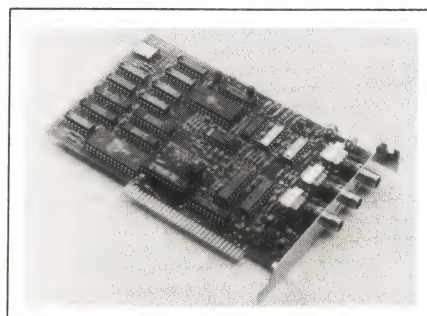
- Contains a multiprotocol SDLC adapter
- Conforms to Bell 201C standard for 2400-bps communication

The AdaptModem/2 model 2400 modem board for IBM's Micro Channel Architecture integrates a 2400-bps modem that conforms to the Bell 201C standard with a multiprotocol SDLC adapter. When used with the company's AdaptSNA software, the board supports PS/2-to-host communications sessions through the following SNA protocols: interactive 3270, cooperative processing Logical Unit 6.2 (LU6.2/APPC), batch Remote Job Entry (3770/

RJE), and program-to-program Logical Unit 0 (LU0). The modem portion of the board includes auto-dial and autoanswer features. The AdaptSNA software conforms with IBM's device-independent SAA. Board, \$625; AdaptSNA software, \$245 to \$785.

**Network Softwork Associates Inc.**, 22982 Mill Creek, Laguna Hills, CA 92653. Phone (714) 768-4013.

Circle No 418



## VOICE PROCESSOR

- Board for IBM PC/XT and PC/AT has two audio inputs
- Compressed 4-bit ADPCM data audio inputs for disk recording

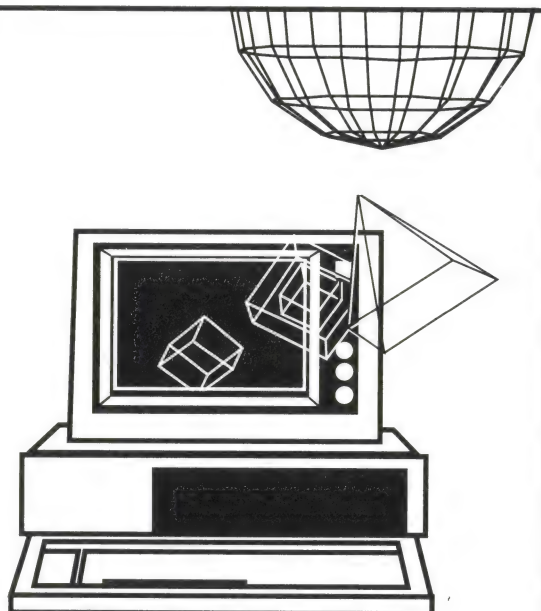
The Model VP635 voice-processor board for the IBM PC/XT, PC/AT, and 80386 compatible computers features two audio inputs that can be attenuated or mixed under software control. The inputs are com-

pressed into 4-bit adaptive differential pulse-code-modulation data for recording on disk and subsequent playback. The bandwidth of audio output channel is 20 Hz to 7 kHz. The 3/4-size board can sample the audio inputs at 8-, 12-, and 16-kHz with 10-bit resolution and can also randomly access recorded data on a floppy- or hard-disk drive. It has RCA phone-jack connectors for the inputs and output, and its power requirements are 500 mA from 5V, 40 mA from -12V, and 20 mA from 12V. The inputs and output are transformer isolated. The board

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comes with menu-driven software for recording, filing, and playback of audio files under keyboard control. \$310 (100).

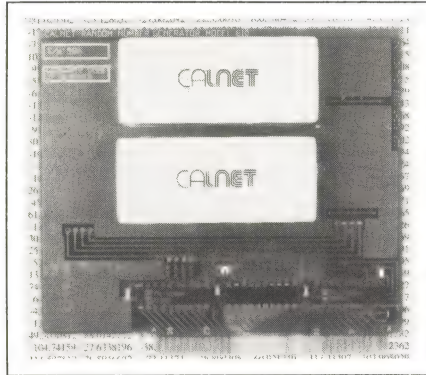
**Antex Electronics Corp.**, 16100 S Figueroa St, Gardena, CA 90248. Phone (800) 621-0849, ext 350; in CA, (213) 532-3092. TWX 900-344-7381. FAX 213-532-8509.

**Circle No 419**

## NUMBER GENERATOR

- Truly random for IBM PC/XT and PC/AT computers
- Each generated bit derives from a Johnson noise source

The Model RNG-810 random-number generator card for the IBM PC/XT and PC/AT generates truly random numbers, using a proprietary noise technology. Each generated bit derives from independent sources based on Johnson noise. The unit requires no starting value (or seed), and each number is inde-



pendent from any previous numbers. Unlike algorithmic-based number generators, the board's numbers are not pseudorandom. Since there are no repeating patterns and no hardware or software algorithms, the cycle size is infinite. The user can generate 10,000 random numbers/sec. \$350.

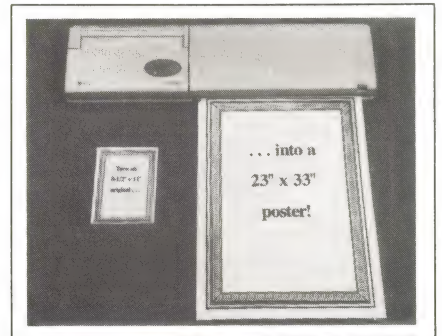
**Calnet Electronics Inc.**, Box 13113, Kanata, Ont K2K 1X3. Phone (613) 831-0424. FAX 613-831-1936.

**Circle No 420**

## POSTER PRINTER

- 23×33-in. poster from an 8½×11-in. document
- Can enlarge drawings in approximately 70 sec

The PosterPrinter can generate posters as large as 23×33-in. from 8½×11-in. documents or smaller. It blows up a drawing in approximately 70 sec. You simply have to insert the original, press a button, and the device prints the poster. The printer doesn't require any ink or toner; you just snap in a roll of printer paper and the unit is ready.



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**Varitronic Systems Inc.**, 300 Interchange Tower, 600 S County Rd 18, Minneapolis, MN 55426. Phone (612) 542-1531.

**Circle No 421**

## TAPE SUBSYSTEM

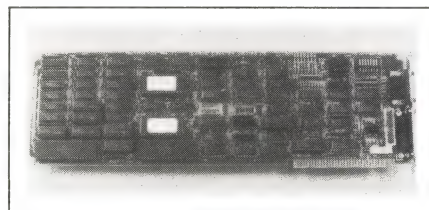
- Can store 2.3G bytes of data on an 8-mm video cassette
- Front-panel LEDs indicate ECC rate

The CTS-8000 helical-scan tape subsystem can store as much as 2.3G bytes of data on an 8-mm video cassette. The metal-particle tape in-

side an 8-mm cartridge has a higher coercivity than other magnetic storage media and is therefore less prone to demagnetization from stray magnetic fields. The unit uses a Reed-Solomon product code for error checking and correction. The uncorrectable error rate is  $<1$  in  $10^{13}$  bits. The unit also features front-panel LED readouts that indicate the remaining tape length and the ECC rate for evaluating the tape quality. The system can transfer data at a 256k-bps sustained rate and contains a 256k-byte data buffer. The unit works with standard DEC device drivers and comes with a dual-width Q Bus or a quad-width Unibus controller card. Versions are also available for Apple, IBM, and Sun computers. \$7495.

**Transitional Technology Inc.**, 1411 N Batavia, Suite 203, Orange, CA 92667. Phone (714) 744-1030. FAX 714-744-2497.

**Circle No 422**



## APPLE-TO-PC BOARD

- Lets an IBM PC/XT or PC/AT execute Apple IIe software
- Has an Apple-compatible 5¼-in. disk-drive port

The Trackstar E board for the IBM PC/XT and PC/AT executes and displays Apple IIe software. The company claims the board is 98% compatible with existing Apple IIe software. The 65C02-based board has 128k bytes of system memory, an Apple-standard 1-MHz clock, a 40- or 80-column video adapter, an Apple-compatible 5¼-in. disk-drive port, and Apple IIe- and IIc-compatible game ports. The board lets you use the IBM PC hard disk for Apple files. It also supports as

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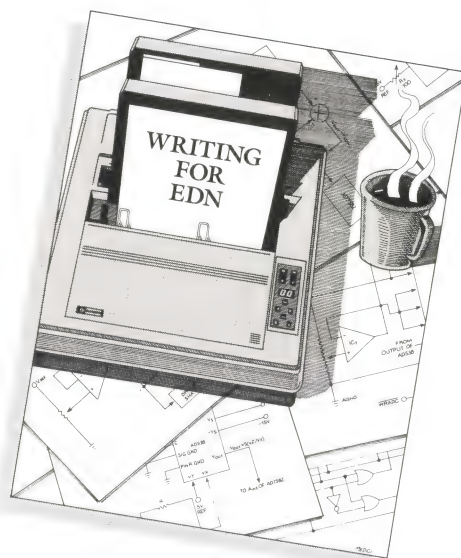
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many as four disk drives for Apple ProDOS, as many as two disk drives for Apple DOS 3.3, LANs, Apple serial and parallel ports, and IBM MDA, CGA, and Hercules monitors. The board can also transfer text or binary files between MS-DOS and Apple DOS 3.3/ProDOS, including spreadsheets. Using two keystrokes, you can switch between the MS-DOS and the Apple modes. \$445.

**Diamond Computer Systems,**  
470 Lakeside Dr, Sunnyvale, CA  
94086. Phone (408) 736-2000.

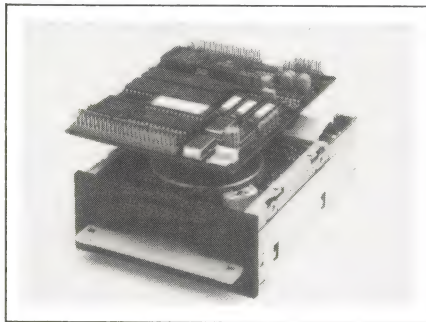
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## DISK CONTROLLER

- Connects floppy-disk drives to SCSI bus
- Operates with a variety of different media formats

The CC-102 floppy-disk controller card allows you to connect as many as four 3½-in. or 5¼-in. floppy-disk drives to the SCSI bus. You can also use it to interface the drives to an RS-232C data link. Incorporating a 6809 µP, a 6844 DMA controller, and a 32k-byte data buffer, the board operates at data transfer rates of 1.5M bytes/sec on the SCSI bus or 38k baud on an RS-232C link. When you use it with an RS-232C link, firmware provided with the board allows you to implement checksum-based error-checking routines. You can operate the floppy-disk drives with a number of media formats, including single- or double-density modes with sector sizes of 128, 256, 512, 1024, 2048, or 4096 bytes. An initialization table, which is transmitted to the controller card over the SCSI or RS-232C interface, controls the media format. The card's SCSI interface supports the SCSI disconnect/reconnect option and has single-ended outputs that can drive as much as 6m of cable. The CC-102 draws a maximum current of 1.7A from its 5V supply. Gld 610 (100).

**CompControl bv,** Stratumseindijk  
31, 5600 AD Eindhoven, The Neth-



erlands. Phone (040) 124955. TLX 51603.

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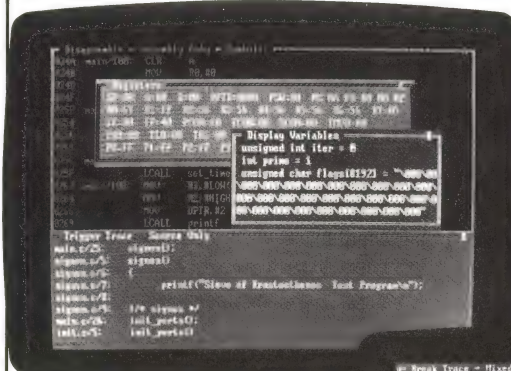
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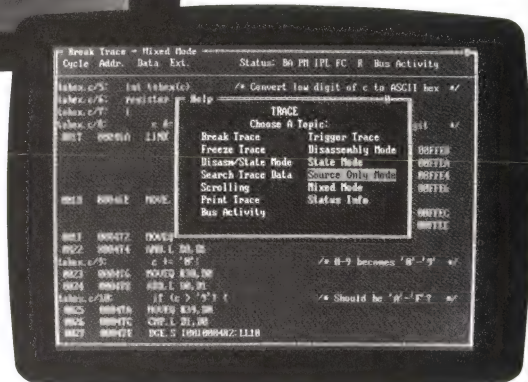


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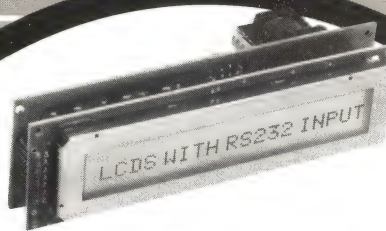
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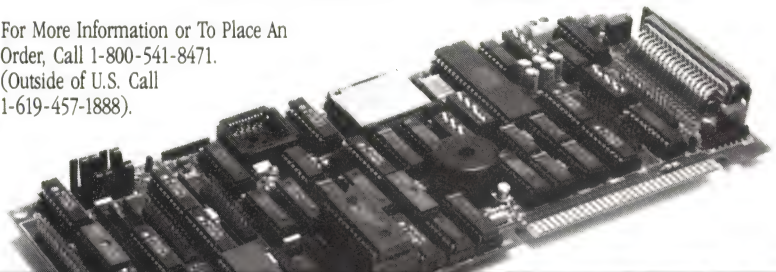
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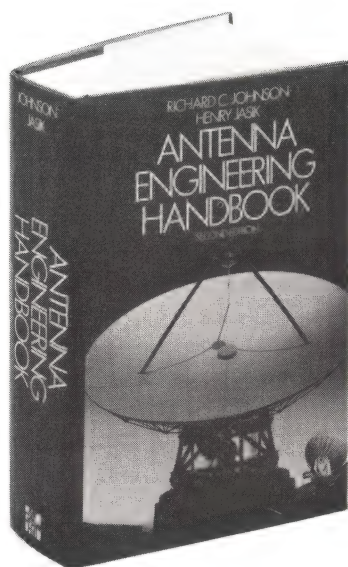
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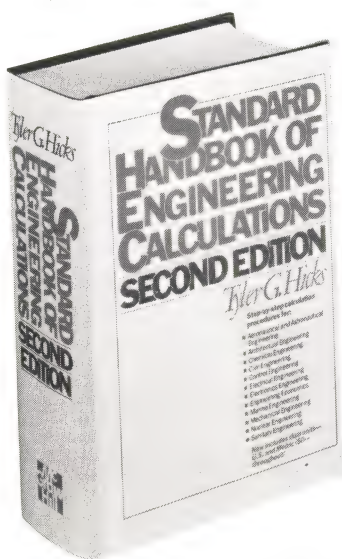
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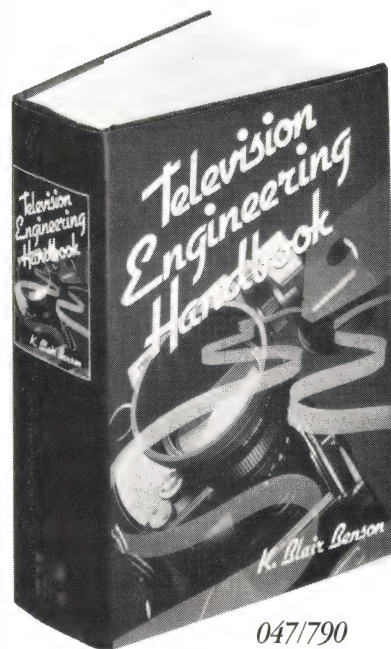
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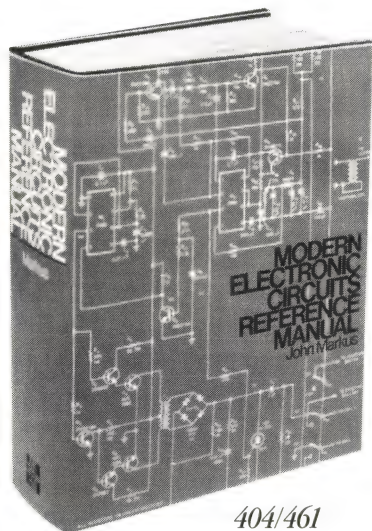
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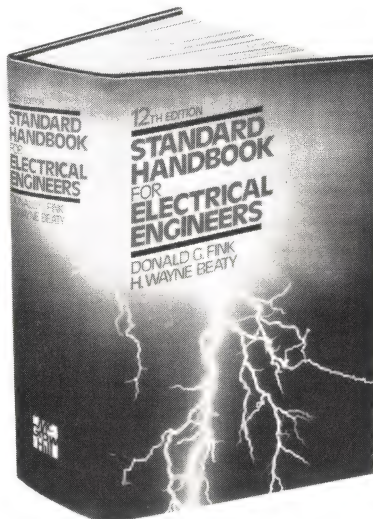
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phases of routing, Autorouter optimizes, rips up, and reroutes vias for each network. During the final passes, the router centers traces in the routing channels and further optimizes vias. For critical traces, you can prewire before starting the autorouter. To operate the HiWire Plus Autorouter, you need the HiWire Plus CAD package and an IBM PC/XT, PC/AT, or PS/2 with 640k bytes of RAM. A utility program can translate FutureNet, OrCAD, Schema, and Tango netlists; Algorex, Cadnetix, and SciCards netlist translators are being developed. \$895.

**Wintek Corp.**, 1801 South St, Lafayette, IN 47904. Phone (317) 742-8428. FAX 317-448-4823.

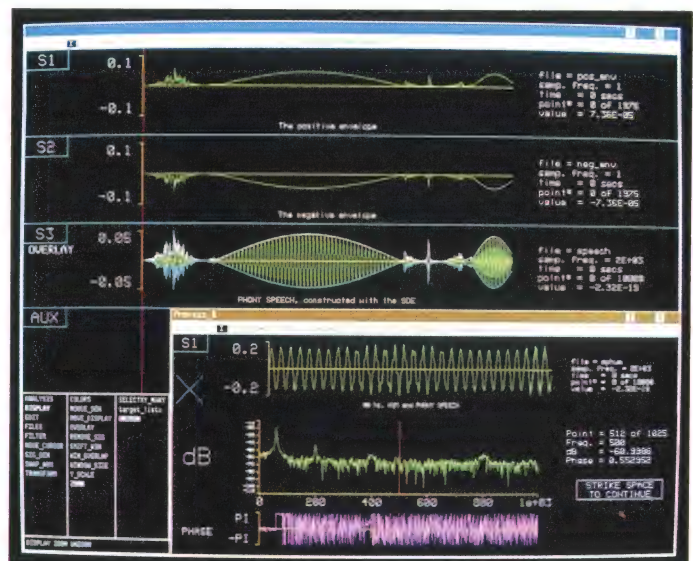
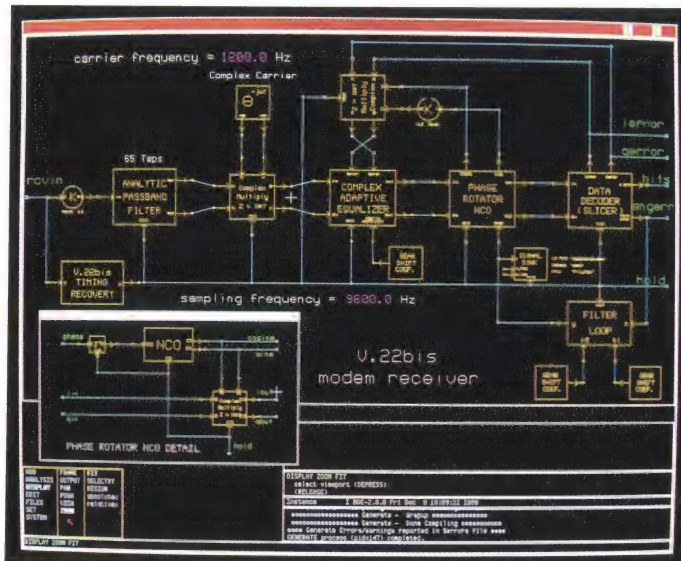
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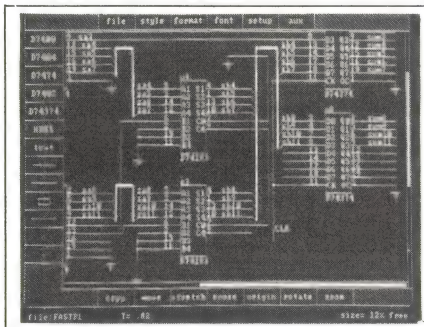
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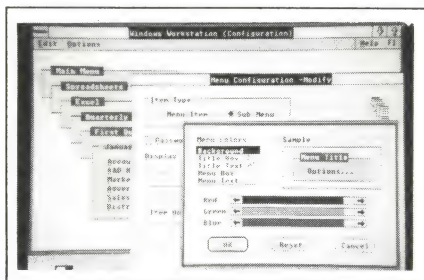
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- Use less than 12k bytes of RAM
- Support Novell's Netware

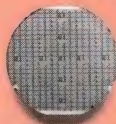
The Windows Workstation is a family of local-area-network utilities for users of Microsoft's Windows. Windows Menu is an applications organizer that provides a seamless inter-

face for sharing Windows-compatible applications over the network. Windows Menu allows you to build colorful custom menus, using sub-menus, multiple levels of password protection, and context-sensitive help messages. Windows Print permits access to all Netware printing resources from within the Windows environment. Secure Station provides security and privacy to applications without making you leave Windows or log off; you can lock your workstation to prevent tampering or viewing while applications run in the background. Screen Saver prevents images from burning into the CRT, and Windows Intercom delivers messages to the workstation. Windows Menu and Windows Print, \$1195.

**Automated Design**, Windows Resource Center, 133 Johnson Ferry Rd, Suite 112, Atlanta, GA 30068. Phone (404) 988-0969.

Circle No 389

# HOLT IS LOOKING FOR SOME CUSTOMERS IN A HURRY.



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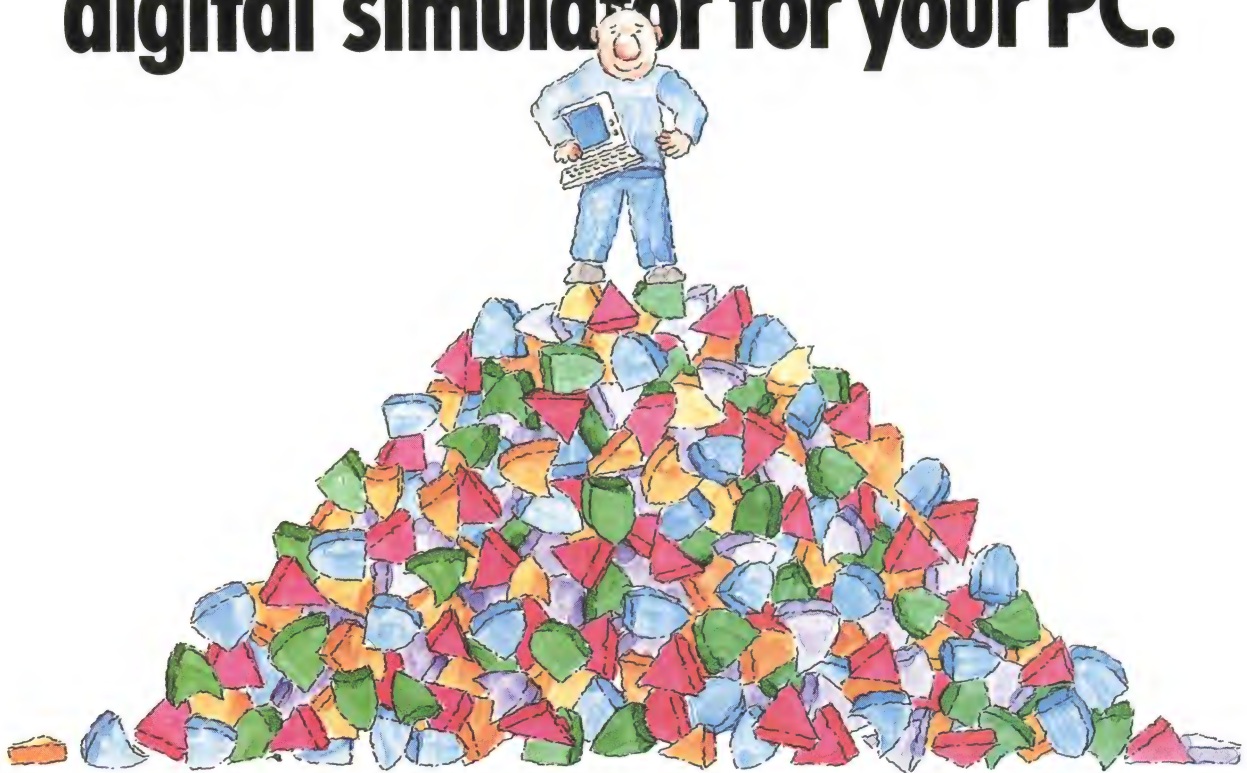
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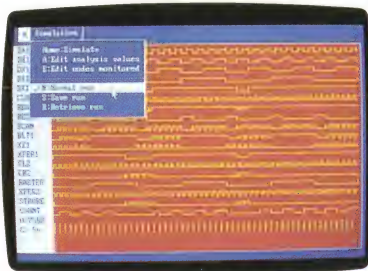
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## The CAE tool with a 10,000-gate digital simulator for your PC.



Spectrum Software's MICRO-LOGIC II<sup>®</sup> puts you on top of the most complex logic design problems. With a powerful total capacity of 10,000 gates, MICRO-LOGIC II helps engineers tackle tough design and simulation problems right at their PCs.

MICRO-LOGIC II, which is based on our original MICRO-LOGIC software, is a field-proven, second-generation program. It has a high-speed event-driven simulator which is significantly faster than the earlier version.



*Timing Simulator*

The program provides you with a top-notch interactive drawing and analysis environment. You can create logic diagrams of up to 64 pages with ease. The software features a sophisticated schematic editor with pan and zoom capabilities.



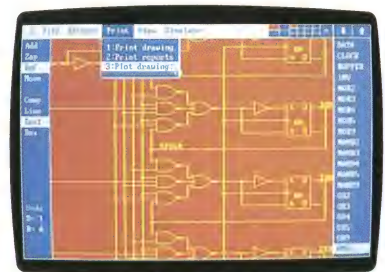
*Shape Editor*

A 200-type library of standard parts is at your fingertips. And for a new high in flexibility, a built-in shape editor lets you create unique or custom shapes.

MICRO-LOGIC II is available for the IBM<sup>®</sup> PC. It is CGA, EGA, and Hercules<sup>®</sup> compatible and costs only \$895 complete. An evaluation version is available for \$100. Call or write today for our free brochure and demo disk. We'd like to put you in touch with a top digital solution.

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**spectrum**

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(408) 738-4387

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## RELIABILITY TOOL

- Based on MIL-HDBK-217E
- Generates customized reports

The Reliability Prediction Program, RPP-V-3.1, is an interactive program that presents component failure rates when you enter data through form-fill menus. You can enter your own generic parts data or you can use the data from libraries. Further, you can set defaults for the quality level of all parts, for junction temperature of ICs, and for the voltage applied to transistors and diodes. Editing features let you make changes and replicate and export data. RPP-V-3.1 runs on DEC VAX computers under VMS 4.6 or higher. Optional features include a batch-loader program and a component stress-analysis program. The standard Reliability Prediction Program includes library maintenance and global-change features and comes with a 30-day money-back guarantee. First-year charge for the basic program, from \$6000; annual renewal charge, 20% of the first-year charge.

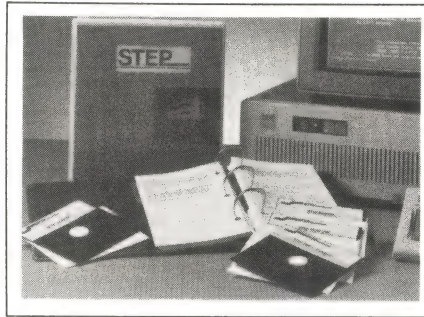
**Powertronic Systems Inc.**, Box 29109, New Orleans, LA 70189. Phone (504) 254-0383.

**Circle No 390**

## RISC TOOL SET

- Includes hardware-development prototyper
- Provides C compiler, source-level debugger, and cross-assembler

The 29000 RISC Support Tools package contains software development tools that work in conjunction with the vendor's Adapt29K hardware-development and prototyping tool for AMD's 29000 RISC processor. The package consists of a C compiler, a source-level debugger, and a cross-assembler. The C29K is a globally optimizing C compiler that conforms to the proposed ANSI C standard and includes run-time libraries, an assembler, a linking loader, and an object-module librarian. The XRay29K debugger



lets you set breakpoints at C statements or line numbers, or at assembly-language instructions or memory references. The Step29K cross assembler is a relocating macroassembler, which comes with a linking loader, object-module librarian, and math support. Both the debugger and the cross-assembler run on a variety of host computers such as IBM PCs and compatibles, engineering workstations, and VAX minicomputers. You can download object files to the 29000 target in hex formats and other structures via a serial link. The Adapt29K hardware prototyper provides a 4096 x 128-bit trace buffer that captures 29000 bus signals at speeds as high as 40 MHz. ROM-resident monitor software in the Adapt29K lets you set and display registers, disassemble and display captured bus activity, and trace instruction execution in single or multiple steps. XRay29K source-level debugger, \$1780; Step29K cross-assembler, \$1000; Adapt29K prototyper, \$8500; C29K compiler, \$1850; 29000 RISC Support Tools package, \$12,130.

**Step Engineering**, Box 3166, Sunnyvale, CA 94088. Phone (408) 733-7837. FAX 408-773-1073.

**Circle No 391**

## PC-BOARD DESIGN TOOL

- Features layout editor, router, and board-analysis program
- Generates photoplot image

Scepter PCB is a pc-board production tool suitable for use with multi-layer analog, digital, and surface-mount boards. The layout editor lets you define component libraries,

designate digital and analog packages, and assign I/O pins without the use of text files. The program can place as many as 2000 schematic elements automatically and imposes no limit on the number of components you place manually. Scepter PCB can route as many as 5000 signal nets automatically or 64,000 nets interactively; it can accommodate packages with as many as 2000 pins and can display and edit as many as 50 layers at one time. The Graphical Routing-Feasibility Analysis program uses colors to indicate routing density, allowing you to quickly identify those areas on the board where potential routing-disconnects may occur. The design-rule checker not only identifies trace-to-trace spacing, but also examines all graphics primitives and identifies violations. For example, it accurately calculates clearances around tapered polygons and identifies traces that may be shorted by any text or logos that are present on the board. \$19,999 to \$29,999.

**Royal Digital Scepter Systems**, 2855 Kifer Rd, Santa Clara, CA 95051. Phone (408) 980-9492.

**Circle No 392**

## DEBUGGER

- Works with Cobol, C, Fortran, and other languages
- Lets you debug mixed-language programs

CodeWatch is an interactive, source-level debugger that you can use with any of the vendor's language compilers running on 80386- or 680X0-based machines under Unix or Xenix. The debugger lets you track variables in the source code, set breakpoints, control execution, and perform all common debugger functions. Further, you can use the debugger with programs that embody routines written in more than one language. A macro feature lets you create customized debugger commands that you can use interactively or from a command file. Action lists let you group



several debugger commands into a unit for execution at a breakpoint, at each step, or at tracepoints. From \$495 to \$2495, depending on the host configuration.

**Language Processors Inc.**, 959 Concord St, Framingham, MA 01701. Phone (508) 626-0006.

**Circle No 393**

## NOISE CALCULATOR

- Uses two methods to calculate op-amp noise
- Runs on IBM PCs and compatibles

Noise.Exe, a general-purpose program that calculates noise in op-amp circuits, takes into account both noise due to the source resistors and noise due to op-amp parameters. The program runs on any IBM PC or compatible and is completely menu-driven. It prompts you for all information it needs, but if you don't supply op-amp parame-

ters, it uses built-in default values. The program optimizes the source impedance for your application and generates a table of the vendor's op-amps that will meet your requirements. The program is available from the vendor at no charge.

**Linear Technology Corp.**, 1630 McCarthy Blvd, Milpitas, CA 95035. Phone (408) 432-1900. FAX 408-434-0507.

**Circle No 394**

## MODELING LANGUAGE

- Lets you formulate optimization problems
- Includes error-checking and -reporting features

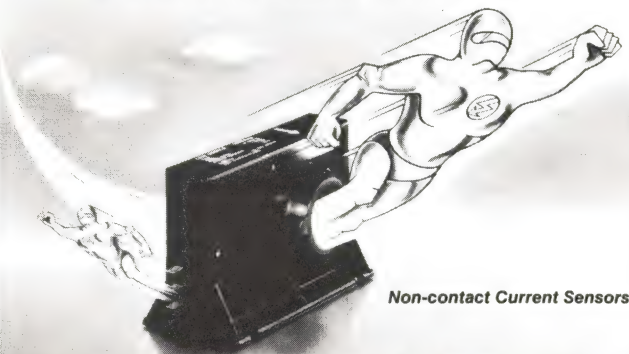
GAMS (General Algebraic Modeling System) is a high-level programming language that lets you formulate complex optimization problems by means of concise algebraic statements. When constructing models, you can use arithmetic and rela-

tional operators, indexing, functions, and exception-handling logic. You can enter data in basic forms, either by direct assignment or in table form. You can specify data transformations in algebraic form, and the program will perform the calculations. The complete package consists of the GAMS compiler, which has extensive error-checking and -reporting facilities and built-in report-writing features; the solver Minos for large linear and nonlinear problems; and the solver Zoom-XP for mixed-integer problems. PC version, \$1600; workstation version, \$3200; mainframe version, \$6400.

**The Scientific Press**, 507 Seaport Ct, Redwood City, CA 94063. Phone (415) 366-2577.

**Circle No 395**

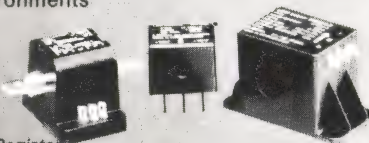
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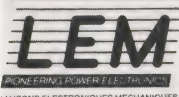
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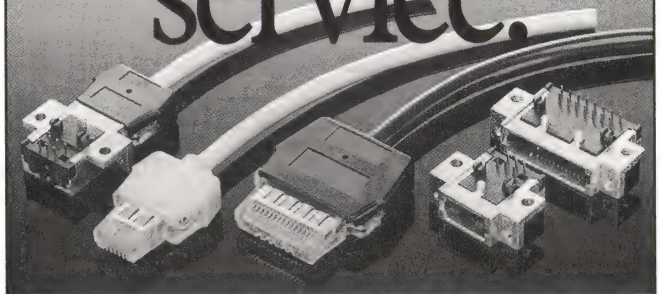
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**CIRCLE NO 31**

## Plug into service.



Need a low profile I/O connector system you can plug in and forget? Take a look at Compu-Shield. It's a fully modular system of demonstrated reliability, featuring a proven contact system. Contacts are on .050 in. centers, with 360° shielding against EMI/RFI for data busing. Selective gold plating in the contact area maximizes conductivity while keeping costs down. The spring contacts are totally enclosed and tension pre-loaded.

The installer and user friendly Compu-Shield connector system is available as separate units, or as complete cable assemblies to your precise specifications. Call or write today for full details.



**COMPU-SHIELD CONNECTOR SYSTEM**  
21001 Nordhoff St., Chatsworth, CA 91311 • (818) 341-4330

**CIRCLE NO 32**



# NEW PRODUCTS

## TEST & MEASUREMENT INSTRUMENTS

### 2-GHz DATA SOURCE

- Generates 64-bit programmable words
- Produces 127-bit pseudo-random patterns

The DG3020 digital data generator produces programmable patterns with lengths from  $2^0$  to  $2^6$  bits. You can create the patterns via the front panel or download them through an RS-232C port. The generator can also produce 127-bit pseudo-random bit sequences and store 10 data patterns and ten clock frequencies. Based on a programmable phase-locked loop synthesizer, the clock operates from 50 MHz to 2 GHz. Output amplitude varies from 0.5 to 2V, and you can adjust base-line offset from -2 to +1V. Rise and fall times are 180 psec typ, jitter is <50 psec, and output impedance is 50Ω. The instrument also produces four additional ECL-compatible outputs, each shifted in phase by  $\frac{1}{4}$



clock period. \$24,000. Delivery, 8 to 12 weeks ARO.

**Microwave Logic, 2 Evergreen**

Rd, Natick, MA 01760. Phone (508) 655-6088. FAX 508-663-1573.

**Circle No 400**



### HANDHELD DSO

- Provides two floating-input channels with 10-MHz bandwidth
- Weighs  $4\frac{1}{2}$  lbs

The 222 digital-storage oscilloscope (DSO) has a 10-MHz bandwidth and is small enough to fit in your toolbox. With its built-in battery, the scope weighs  $4\frac{1}{2}$  lbs and measures  $3\frac{1}{2} \times 6\frac{1}{4} \times 10$  in. Each of the two y-axis inputs is ohmically isolated from the other input and the chassis. The scope samples to 8-bit precision at 10M samples/sec; at fast sweep speeds, it automatically

switches to equivalent time sampling. Despite its small size, the 222 incorporates many conveniences found in full-size DSOs—for example, storage and recall of control setups. An RS-232C port allows you to control the scope from a remote terminal or computer and lets you upload captured waveforms. \$2350.

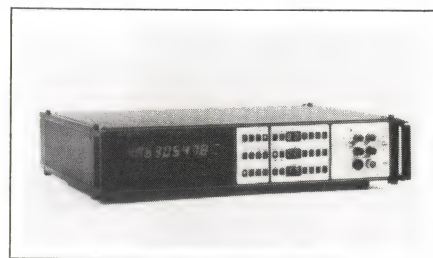
**Tektronix Inc, Box 1700, Beaverton, OR 97075. Phone (800) 426-2200.**

**Circle No 401**

### 8½-DIGIT DMM

- Measures with  $\pm 0.0004\%$  accuracy and  $\pm 0.0001\%$  stability
- Accommodates 4-pole, 20-channel scanner

The 6048 8½-digit DMM uses multi-ramp integration in its A/D converter to achieve  $\pm 0.0004\%$  measurement accuracy and  $\pm 0.0001\%$  stability. The instrument makes

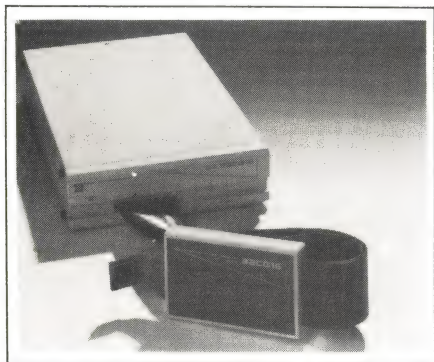


full-scale voltage measurements from  $\pm 0.2$  to  $\pm 1000$ V and uses a 4-wire technique to make full-scale resistance measurements from 200Ω to 200 MΩ. The meter can accommodate a 4-pole, 20-channel scanner and has firmware that facilitates electronic calibration, self testing, and temperature measurement. An IEEE-488 interface is standard equipment. \$5300.

**Hart Scientific, Box T, Provo, UT 84603. Phone (800) 438-4278; in UT, (801) 375-7221. FAX 801-373-8184.**

**Circle No 402**





## NS32CG16 EMULATOR

- Connects to IBM PC/AT host via SCSI bus
- Includes 512k bytes of emulation RAM

The NSS-ISE-CG16 hardware and software emulator interfaces to an IBM PC/AT or compatible host via a SCSI bus. It works with the vendor's NS32CG16 32-bit printer/display processor and supports target systems containing NS32081 or NS32381 floating-point units and systems with the DP8510 bit-

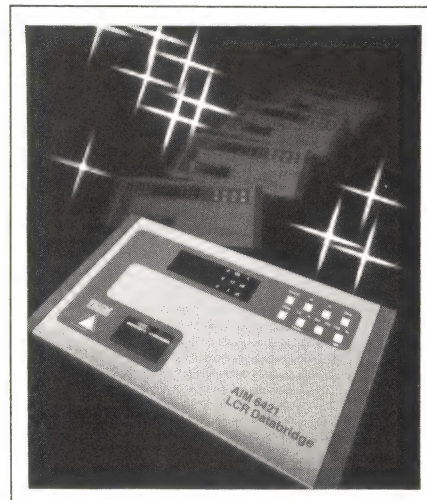
aligned, block-transfer (Bit BLT) processing units. The emulator includes 512k bytes of overlay RAM, which you can expand to 1M byte. It supports two hardware breakpoints based on any of 16 predefined events. In addition, there are 36 software breakpoints. The emulator also supports selective tracing and triggering by events; the trace buffer is 2k frames deep. \$16,248.

**National Semiconductor Corp.**  
Box 58090, Santa Clara, CA 95052.  
Phone (408) 721-3219. TLX 346353.  
**Circle No 403**

## COMPONENT TESTER

- Measures component parameters at three test frequencies
- Has an optional IEEE-488/RS-232C remote-control interface

At test frequencies of 100 Hz, 1 kHz, or 10 kHz, the 6421 component tester measures inductance, capacitance, resistance, dissipation factor,



and Q-factor with 0.2% accuracy. The instrument displays measured values to 4-digit resolution and prompts the operator when measurements are made outside recommended measurement conditions. Standard features include automatic recognition of component type; series or parallel equivalent-circuit modes; a 4-terminal, integral

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**MATSUO ELECTRONICS**

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Huntington Beach FAX (714) 960-6492  
California 92648 TWX (910) 596-1828

**CIRCLE NO 33**

## More for less.



Here's a low cost, high density commercial connector that's really rugged and reliable. Made of high impact thermoplastic, its excellent strength-to-weight ratio offers optimum durability. There's no corrosion to worry about, and it's UL and CSA approved. Available in bulkhead or square flanges, it is quick and easy to mount. The light weight, compact and quick connect/disconnect features make it easy to work with.

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**CIRCLE NO 34**

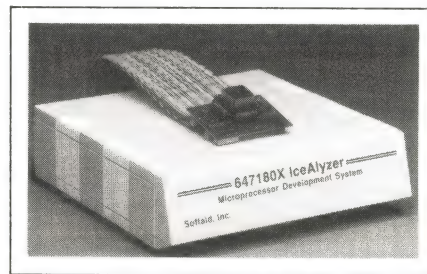


test fixture; 2V biasing to test electrolytic capacitors; and a zeroing facility that allows you to compensate stray capacitance in external test leads. Optional accessories include component test leads with Kelvin clips, probes for handling surface-mount devices, and BNC connector adaptors. An interface option that provides the instrument with

IEEE-488 and RS-232C interfaces, and software that allows you to log and analyze measured values on a PC are also available. £745.

**Prism Electronics Ltd**, Burrell Rd, Industrial Estate, Saint Ives, Huntingdon, Cambridgeshire PE17 4NF, UK. Phone (0480) 62225. TLX 32303. FAX 0480-494047.

Circle No 404



## 647180X EMULATOR

- Connects to IBM PC or compatible via RS-232C port
- Includes 80k bytes of full-speed static overlay RAM

The 647180X IceAlyzer supports Hitachi's 647180X 8-bit, single-chip, microcontroller, which uses the Z80's architecture and includes 16k bytes of one-time programmable ROM. The emulator provides 80k bytes of static overlay RAM. Of this memory, 16k bytes are write protected during emulation to accurately imitate the PROM on the  $\mu$ C chip. The emulator also includes a real-time trace buffer; it displays the buffer's contents disassembled in 647180X mnemonics. A mask register lets you select addresses to be included in a trace. A software performance analyzer is standard; at any time, you can instruct the analyzer to display the amount of time spent executing a particular area of the program. \$5995; source-level debugger, \$750.

**Softaid Inc**, 8930 Rte 108, Columbia, MD 21045. Phone (800) 433-8812; in MD, (301) 964-8455. TLX 650-265-2092.

Circle No 405

# Turn Good Ideas Into Good Articles

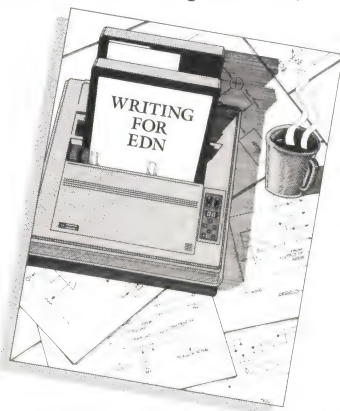
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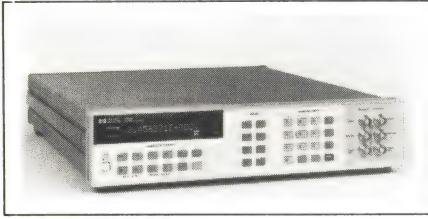


## UNIVERSAL SOURCE

- Generates dc, ac, and arbitrary waveforms
- Provides voltage and current with 6½-digit resolution

The HP 3245A combines a bipolar dc voltage/current source with an arbitrary-waveform generator that has a 4.3-MHz sample rate and produces 1-MHz waveforms. You can set the dc outputs with 6½-digit precision. Maximum voltage is  $\pm 10.25$ V and maximum current is

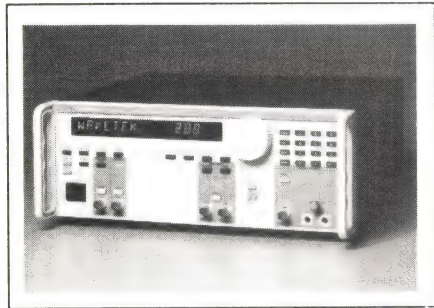




±100 mA. You can define waveforms with as many as 2048 points and store multiple waveforms in nonvolatile RAM. An optional software package includes a library of standard waveforms and facilitates waveform definition, capture, modification and playback. With one channel, \$4200; with two channels, \$6700; software, \$400.

Hewlett-Packard Co, 19310 Pruneridge Ave, Cupertino, CA 95014. Phone (800) 752-0900.

Circle No 406



## FUNCTION GENERATOR

- Provides synthesized outputs from 0.002 Hz to 20 MHz
- Ensures accuracy with 5-sec self-calibration process

The 288 ruggedized function generator features synthesized-frequency outputs from 0.002 Hz to 20 MHz. An automatic calibration routine, which you can invoke from the front panel, takes five sec to perform 40 adjustments. The unit produces a continuous or a triggered output and can amplitude or frequency modulate its output. The generator can also produce a swept-frequency output and can phase lock its frequency to a 20-Hz to 20-MHz signal that you supply. You can set the output impedance to 50, 75, 135 or 600Ω and obtain either a single-ended or a balanced output. You can set the output amplitude

from 1 mV to 30V p-p with 3-digit precision and set the symmetry of any waveform from 5 to 95%. At 100 kHz, frequency accuracy is 0.01% and sine-wave distortion is 0.5%. \$3295.

Wavetek San Diego Inc, 9045 Balboa Ave, San Diego, CA 92123. Phone (619) 279-2200.

Circle No 407

## POWER METER

- Handles nonsinusoidal voltage and currents
- Analyzes the harmonic content of current waveforms

Suitable for use on distorted waveforms with a crest factor as high as 20:1, the PM1000 ac power analyzer measures ac power, VA, power factor, rms voltage, and rms

## Programmable Linear Phase Filters for A/D Prefiltering Applications

**848DOW Series Combines Constant Delay of a Bessel Filter With The Sharp Attenuation of a Butterworth Filter.**

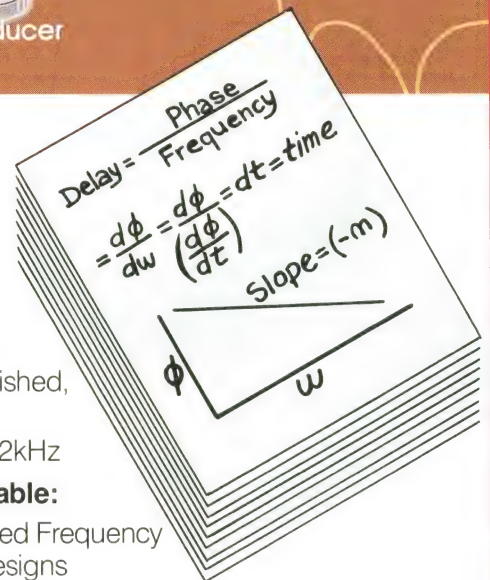
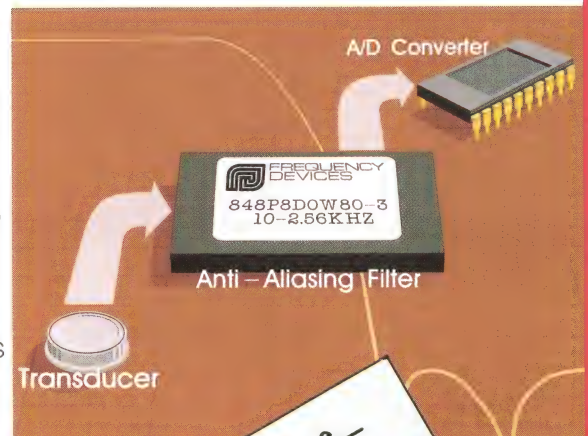
### Features:

- 8 pole, 6 zero linear phase lowpass filters
- Digitally programmable corner frequency
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- Internally latched control lines to store frequency selection data
- Linear phase response to minimize phase distortion
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- Plug in, ready to use, fully finished, filter module
- Five frequency ranges to 51.2kHz

### Other Filter Products available:

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For more information, please call us at  
**508-374-0761**



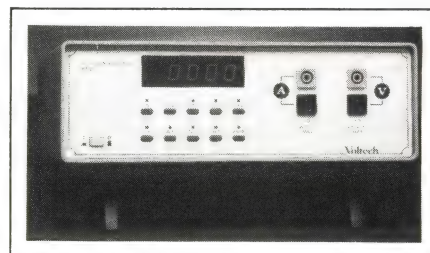
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Haverhill, MA 01830  
(508) 374-0761



current. It can handle rms input voltages ranging from 2 to 700V and rms input currents from 20 mA to 20A. You can extend the input-current capability beyond 1000A by means of an optional precision current transformer. The instrument has a basic voltage accuracy of 0.25%, a current accuracy of 0.5%, and a power-measurement accuracy

of 0.8%. Its frequency range extends from dc to 20 kHz. By performing an FFT analysis, the PM1000 can also analyze the harmonic content of an ac current waveform, allowing you to assess the effectiveness of line-current distortion-correction circuitry. You can also use the instrument to capture the transient in-rush current



that flows into a load when it is switched onto an ac supply. £880.

**Voltech Instruments Ltd**, Step Centre, Osney Mead, Oxford OX2 OES, UK. Phone (0865) 728959. FAX 0865-241386.

Circle No 408

**Voltech Inc**, 10 Cochituate St, Natick, MA 01760. Phone (508) 655-7987. FAX 508-655-7984.

Circle No 409

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Asahi Glass/Optrex

26533 Evergreen Road, Suite 533, Southfield, MI 48076

## VXI BUS COMPUTER

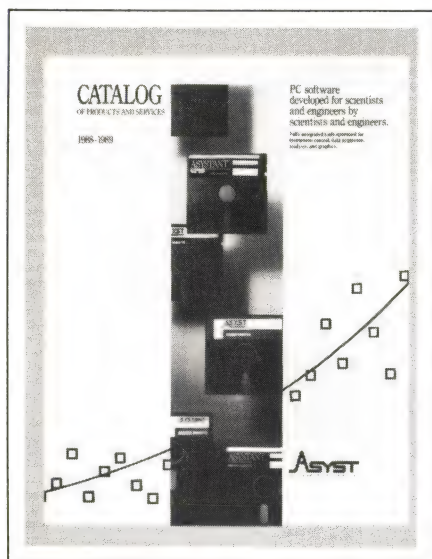
- Functions as 80386-based PC
- Has floppy and hard disks and 640 × 480-pixel graphics

The EPC-2 is a complete 80386-based personal computer in a double-width, C-size VXI Bus (VME Bus extensions for instrumentation) module. The plug-in unit includes a 1.44M-byte 3½-in. floppy-disk drive, a 40M-byte SCSI-interfaced hard disk, a CRT controller that conforms to the VGA (video graphics array) standard, a parallel port, two RS-232C serial ports, a keyboard port, and an IEEE-488 port. The unit can combine the functions of a system controller, a VXI slot 0 device, and an IEEE-488 bus controller. In a package called the EPC-2000, the vendor includes a keyboard, MS-DOS 3.3, Windows/386, a link for migration of programs from a PC to the EPC-2, and a group of software packages collectively called EPConnect 2.0. EPConnect defines a human interface and a program interface to the VXI Bus. It provides both development and run-time support. EPC-2000, \$9550.

**Radix Microsystems Inc**, 19545 NW Von Neumann Dr, Beaverton, OR 97006. Phone (800) 950-0044.

Circle No 410





## Scientific and engineering PC software

The vendor's 20-pg catalog provides a tutorial for PC-based data acquisition and analysis. The publication describes both menu-driven and fully programmable software packages for analysis, statistics, graphics, and data acquisition, and for instrument interface and control. Further, it provides a list of subjects and applications that use the company's products. Comparison charts of all products are included. The catalog also explains the company's training and support services.

**Asyst Software Technologies Inc.**, 100 Corporate Woods, Rochester, NY 14623.

Circle No 430

## Updated version of built-in testability

The 2nd edition of *Design to Test* features expanded guidelines for LSI/VLSI (including ASICs) devices; expanded coverage of merchant-semiconductor-device usage at board level; new coverage of boundary-scan and testability buses and built-in test techniques; and expanded coverage in the analog, checklist, mechanical, and test techniques and strategies chapters. The book is more than 350 pages long with at least 100 pages of new infor-

mation and contains approximately 250 illustrations and tables. The vendor offers a 10-day approval period. \$195; prepaid orders, \$175.50.

**Logical Solutions Technology Inc.**, 310 W Hamilton Ave, Suite 101, Campbell, CA 95008.

INQUIRE DIRECT



## Brochure depicts fixed and mobile test equipment

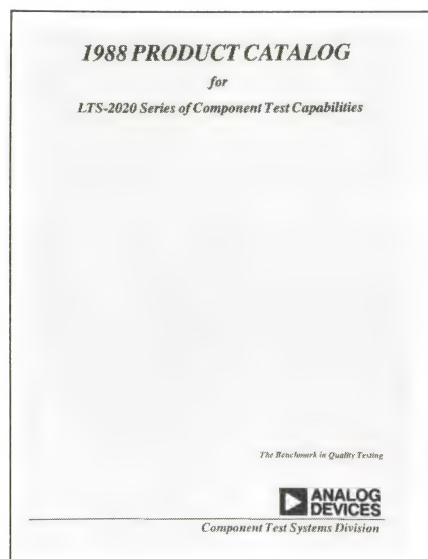
The vendor's 6-pg brochure describes the 1400 Test Facility in its three configurations—mobile, rack-mount, and desk-top. The pamphlet also discusses the chassis, modules, and option cards that are available for use with the test facility. A separate section summarizes information about the various test instruments that can be mounted with a 1400 Test Facility.

**ADC Telecommunications Inc.**, 4900 W 78th St, Minneapolis, MN 55435.

Circle No 432

## Component test system for data-conversion devices

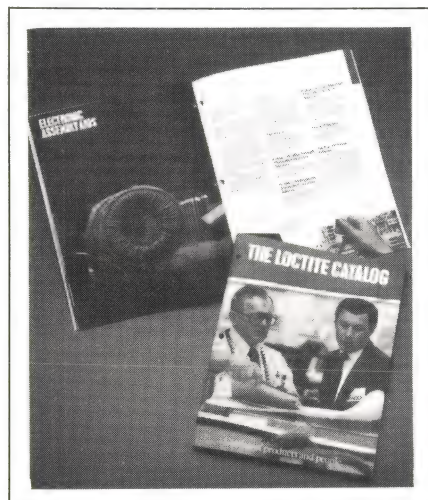
Published in the last quarter of 1988, the company's Product Catalog for LTS-2020 Series of Component Test Capabilities deals with the LTS-2020 benchtop component test system, which tests linear and data-conversion devices, and both ac and dc digital and discrete com-



ponents. The publication describes the LTS system configuration, console specifications and features, and the LTS-2020 development station. An options and supplies section lists peripherals, family boards, socket assemblies, software, interface equipment, and documentation. The book includes specifications, diagrams, photographs, and charts.

**Analog Devices**, 181 Ballardvale St, Wilmington, MA 01887.

Circle No 433



## Wide choice of adhesives, gasketing, and sealants

The vendor's 60-pg catalog contains information about materials for bonding; gasketing; pipe, thread, and hydraulic sealants; retaining cylindrical assemblies; threadlock-



ing devices; electronic assembly aids; solvents, primers, and activators; dispensing systems; and maintenance and repair of equipment. A variety of the products offered meet military specifications, as well as standards set by USDA, USP Class VI for medical applications, Underwriters' Laboratories, and the Nuclear Regulatory Commission. The product selector guide summarizes basic technical information about each item.

**Loctite Corp.**, 705 N Mountain Rd, Newington, CT 06111.

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## Supplement supplies instrument information

This catalog supplement provides a broad selection of brand-name test and measurement instruments, including Tektronix and Fluke. Among the products for testing, repairing, and assembling electronic equipment are DMMs, oscilloscopes, EPROM programmers, probes, breakout boxes, precision hand tools, and tool kits. The source book provides specifications, 4-color photographs, and discount pricing.

**Contact East**, Box 786, North Andover, MA 01845.

Circle No 436

for cable-to-cable or cable-to-equipment applications. This 37-pg guide surveys the vendor's 38999 Series I, II, III connector line. It details the KJA enhanced connector, the KJLB Jam Nut receptacle, and the KJA MIL-STD 1760 lanyard release-plug connector.

**ITT Cannon**, Box 35000, Santa Ana, CA 92705.

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## Personal-computing tools cataloged

*The Catalog of Personal Computing Tools for Scientists and Engineers* contains product reviews by the vendor's technical staff. Most of the products have special ratings, indicating "the best" available for features and performance, and "the only" way to do a job. The catalog offers a 60-day risk-free return period. Featured in this 40-pg 10th edition are the Acquisition Engine; an intelligent 8-port data communications board and an 8-port board for the PS/2; a 3-D CADD system; an "at-speed" individual RAM chip tester; 3-D graphics software; and an expanded line of computer security products.

**Personal Computing Tools Inc.**, 17419 Farley Rd, Los Gatos, CA 95030.

Circle No 438

**LINEAR TECHNOLOGY**

Application Note 23  
April 1987

**Micropower Circuits for Signal Conditioning**

Linear Technology's new 100µA current source, the LT1023, is a precision, low-power, monolithic integrated circuit. It is designed for use in signal conditioning applications where low power consumption is critical. The LT1023 is available in both 8-pin DIP and 14-pin DIP packages. It is also available in a surface-mount package, the LT1023-S.

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- Low output resistance
- Low output voltage
- Low output current

Figure 1: Precision 100µA Current Source with Current Divider

## Designing circuits for batteries or remote sites

The 24-pg application note, AN-23: *Micropower Circuits for Signal Conditioning*, considers circuit design for conditions that require low power consumption, such as battery operation, remote locations, or thermal requirements. The note provides schematics and component values for signal-conditioning circuits that you use with strain gauges, thermocouples, strobed-power strain bridges, thermistor-based current loops, thermostats, A/D and V/F conversion, micro-power switching regulators, and battery backup regulators.

**Linear Technology Corp.**, 1630 McCarthy Blvd, Milpitas, CA 95035.

Circle No 435



## Two listings note FOCT and 38999 Series connectors

This 3-pg, fold-out brochure features the FOCT (fiber-optic ceramic tip) connector and focuses on the interconnect system that's designed



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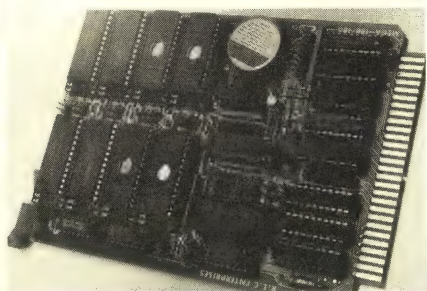
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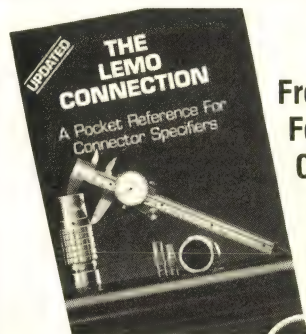
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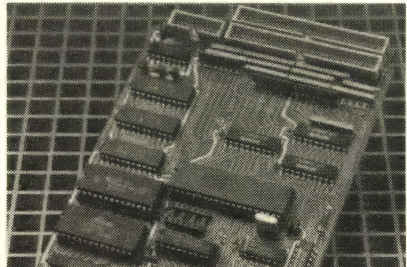
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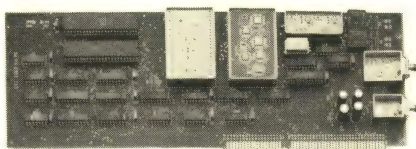
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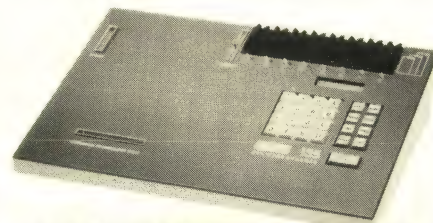
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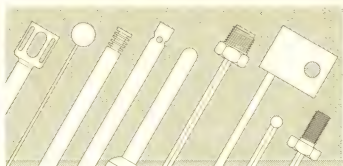
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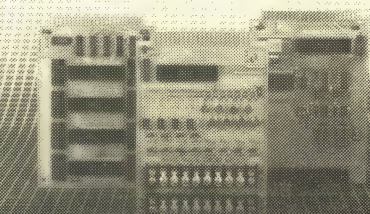
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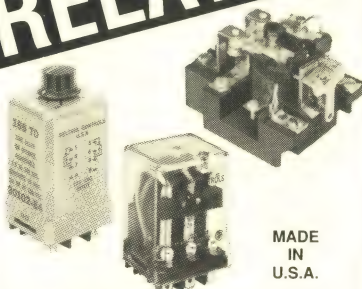
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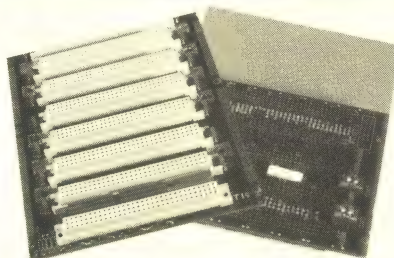
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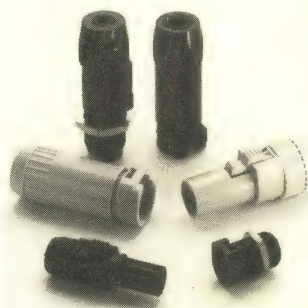
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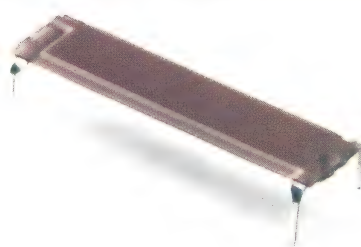
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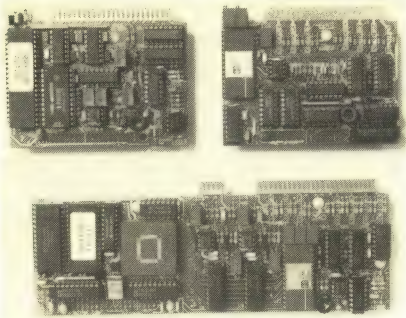


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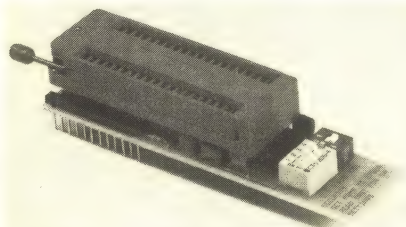


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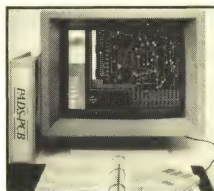
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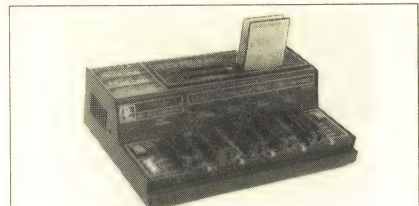
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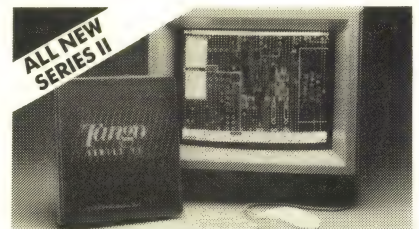
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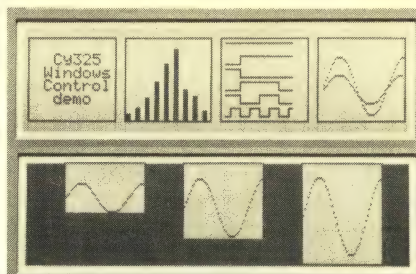
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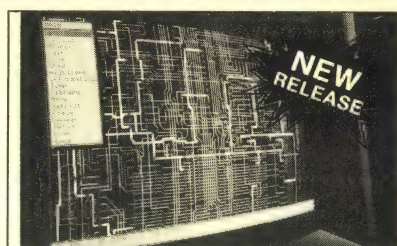
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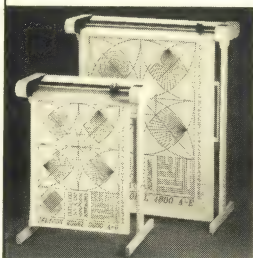
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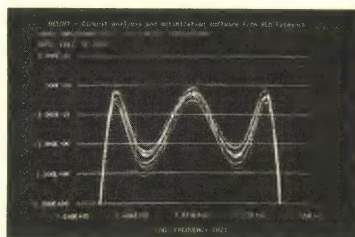
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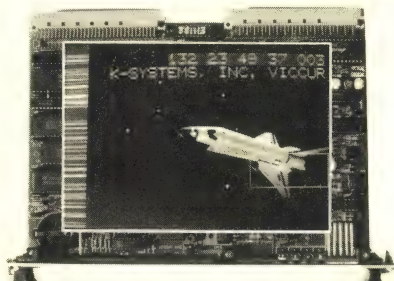
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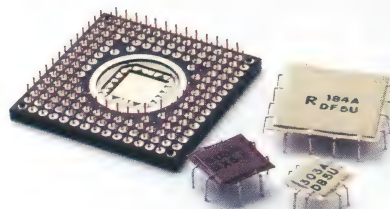
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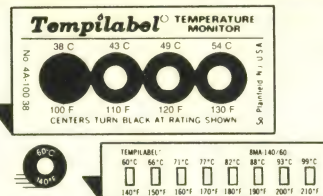
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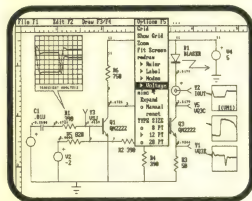
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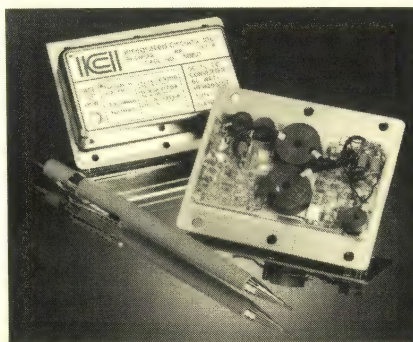
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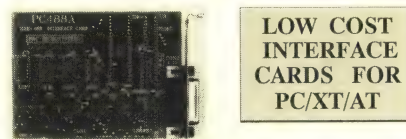


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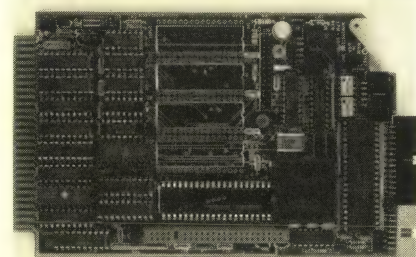
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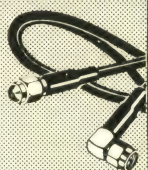
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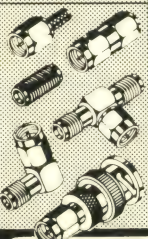
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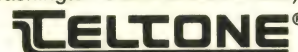
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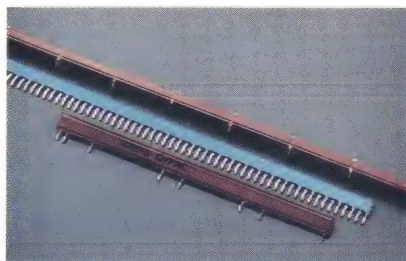
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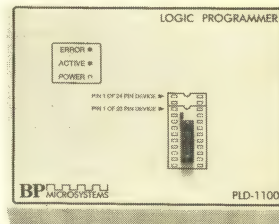
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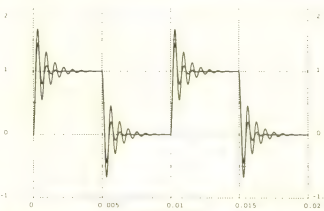


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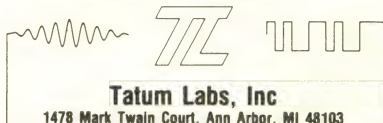
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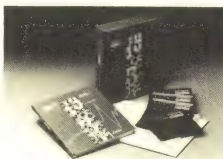
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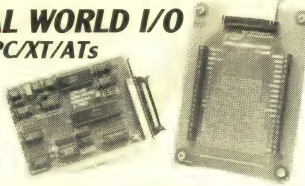
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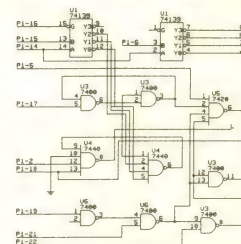
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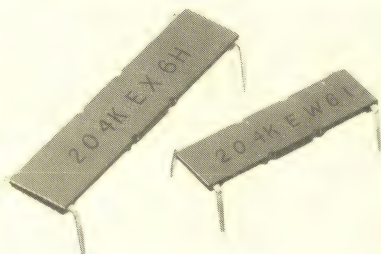
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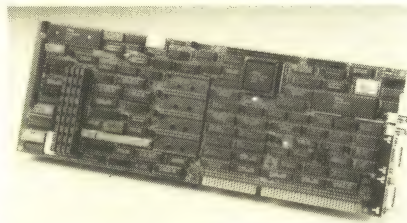


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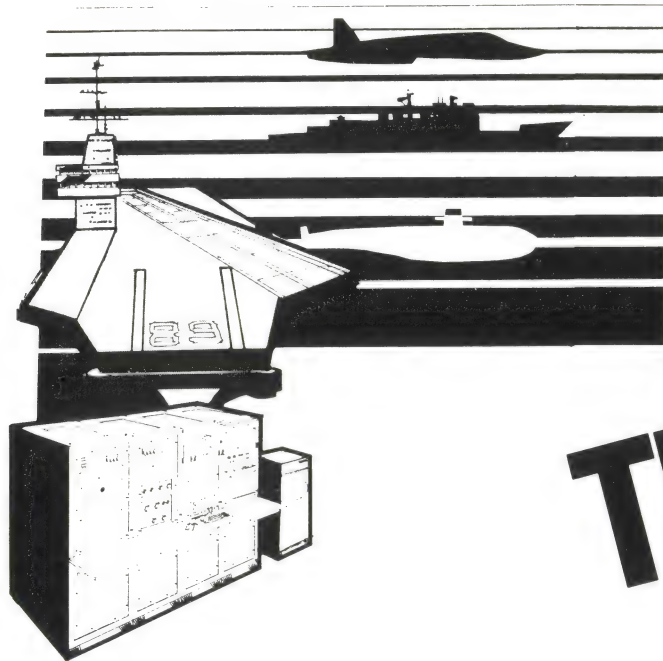
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## ELECTRICAL ENGINEERS Senior & Intermediate

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## SOFTWARE ENGINEERS Senior and Intermediate

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# LOOKING AHEAD

EDITED BY CYNTHIA B RETTIG

## Semiconductor recession is questionable

When asked when the downturn is coming in the semiconductor industry, Dataquest's answer is, "It isn't." The San Jose company concedes that orders have been softening and worldwide shipments during the first half of this year will experience only a small quarterly rate of growth (about 2%), followed by slight decreases for the next two quarters. But its analysts see the total of worldwide shipments increasing this year by 10.2% over last year. This projection assesses the 1989 market at \$54,571,000,000.

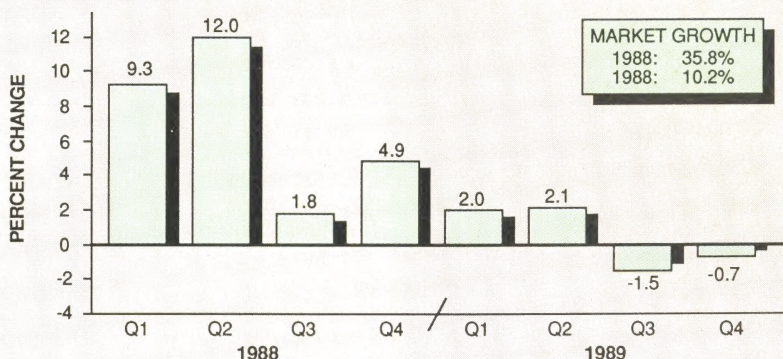
For the 5-year period between 1988 and 1993, Dataquest predicts a compound annual growth rate of 11.9%. Although the company had previously expected a mild industry recession in 1990, it now sees just a fairly flat market for next year, with only a 2% growth over this year.

The analysts base their projections on several key conditions: continued growth in office equipment and computer shipments; a long-term declining trend in US-computer inventory levels among computer OEMs, and the extension of demand into 1989 as a result of last year's dynamic-RAM shortages.

The US market has been slow to recover from past setbacks. However, for the years 1987 to 1992, it should experience a 16% compound annual growth rate. Capital spending predictions outline a 9% growth for this year and a 1% growth for next year, followed by a healthy recovery to 29% and 31%, respectively for 1991 and 1992. Thus the coming slowdown will be short and less severe than past ones. Analysts attribute this development partly to the fact that technology—and not capacity expansion—has been the driving force in the market.

The market-research company

## WORLDWIDE SEMICONDUCTOR SHIPMENT FORECAST



(SOURCE: DATAQUEST INC)

## ESTIMATED WORLDWIDE SEMICONDUCTOR SHIPMENTS (MILLIONS OF US DOLLARS)

|                            | 1988     | 1989     | 1990     | 1991     | 1992     | 1993     | CAGR 1988-1993 |
|----------------------------|----------|----------|----------|----------|----------|----------|----------------|
| <b>TOTAL SEMICONDUCTOR</b> | \$49,509 | \$54,571 | \$55,600 | \$65,230 | \$79,233 | \$86,730 | 11.9%          |
| <b>TOTAL IC</b>            | \$39,403 | \$43,736 | \$44,767 | \$53,295 | \$65,734 | \$73,213 | 13.2%          |
| BIPOLAR DIGITAL            | \$5570   | \$5888   | \$5878   | \$6737   | \$7813   | \$8509   | 8.8%           |
| MEMORY                     | 652      | 627      | 606      | 595      | 546      | 530      | -4.1%          |
| LOGIC                      | 4918     | 5261     | 5272     | 6142     | 7267     | 7979     | 10.2%          |
| MOS DIGITAL                | \$25,250 | \$28,425 | \$29,333 | \$35,487 | \$44,610 | \$49,663 | 14.5%          |
| MEMORY                     | 10,633   | 11,897   | 12,141   | 14,762   | 18,562   | 20,262   | 13.8%          |
| MICRO                      | 7005     | 7862     | 7993     | 9800     | 12,482   | 13,867   | 14.6%          |
| LOGIC                      | 7612     | 8666     | 9199     | 10,925   | 13,566   | 15,534   | 15.3%          |
| LINEAR                     | \$8583   | \$9423   | \$9556   | \$11,071 | \$13,311 | \$15,041 | 11.9%          |
| <b>DISCRETE</b>            | \$7549   | \$7970   | \$7917   | \$8668   | \$9712   | \$9254   | 4.2%           |
| <b>OPTOELECTRONIC</b>      | \$2557   | \$2865   | \$2916   | \$3267   | \$3787   | \$4263   | 10.8%          |
| EXCHANGE RATE YEN/\$       | 130      | 134      | 134      | 134      | 134      | 134      |                |
| EUROPEAN BASKET/\$         | 1.18     | 1.20     | 1.20     | 1.20     | 1.20     | 1.20     |                |

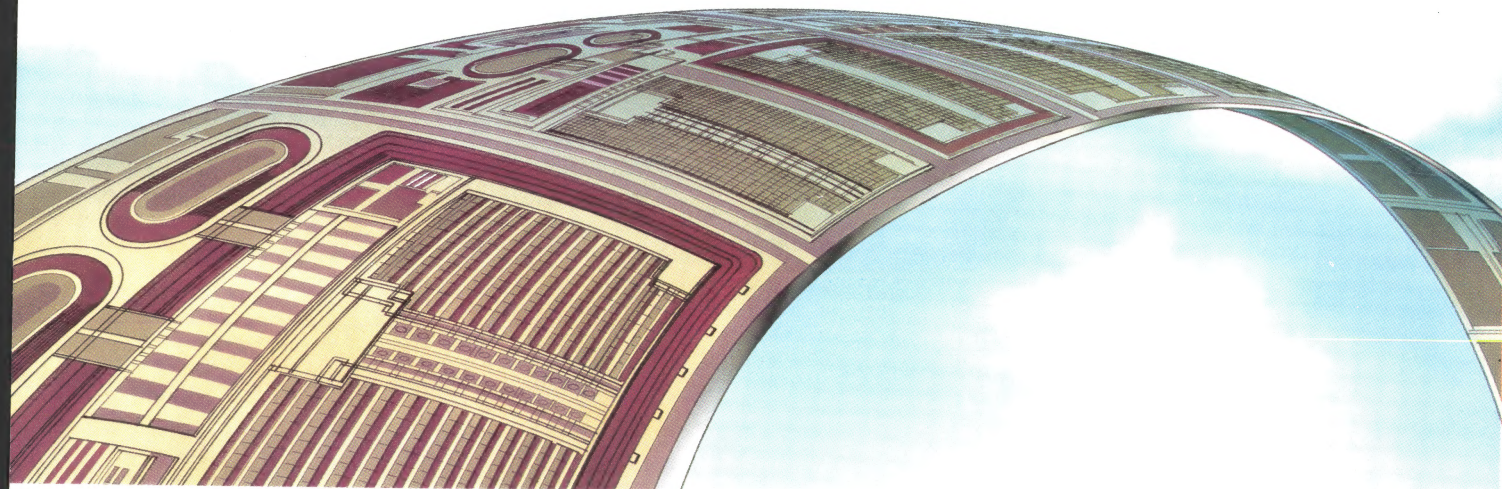
also breaks down the market geographically into four areas: North America, Japan, Europe, and the rest of the world (ROW). In this analysis, the ROW segment is expected to be the fastest growing one. It will surpass Europe in total dollar consumption in 1991 to become the world's third largest market. Japan will be the second fastest growing market, but it will remain the largest in overall size. The

US will be the third fastest in growth and remain the second largest overall.

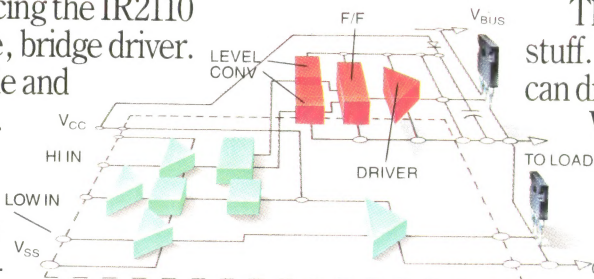
Dataquest stresses that a generally healthy world economy and careful semiconductor manufacturer management of capacity are major considerations that lead to its conclusions that the minimal downturn will be very modest in comparison with the industry's experiences in 1985.



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